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Energy Potential from Livestock and Poultry Wastes in the South

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Abstract

Livestock and poultry wastes could produce significant amounts of biomass energy if conventional energy prices continue to rise. This study estimates the economically recoverable energy available through anaerobic digestion or direct burning of animal wastes in the South for the base year 1980 with projections for 1985 and 1990. Potential thermal energy from livestock and poultry wastes in 1990 could total more than 79.5 trillion Btu, or about 30 percent of the energy from such sources nationwide. The total potential farm value of biomass energy from livestock and poultry enterprises in the South could range from $344 million to $1.08 billion in 1990 depending upon the types of conventional energy displaced. Energy products from these wastes attained their highest value when substituted for LP gas.

Keywords: Biomass energy, Animal wastes, Anaerobic digestion, Energy potential, Direct combustion, Energy values.

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Preface

This report is part of a broader study undertaken by the Economic Research Service and several universities to assess the biomass energy potential from U.S. agricultural and food sectors. The study identifies possible sources of biomass energy on a regional and State level as background information for legislation or policy changes aimed at using some of this energy in the event of an oil shortage or energy crisis. Certain forms of biomass energy will be more feasible than others from a technical or economic standpoint, but it may still be necessary to subsidize farmers or other enterprises in order to provide an incentive for them to invest in technology to use this potential energy. This study was funded in part by the Energy Security Act of 1980.

Units of Measure

Btu = British thermal unit
MMBtu = Million British thermal units
MMcf = Million cubic feet
kWh = kilowatthour
gWh = gigawatthour = 1 million kilowatthours = 3.4153 billion Btu
Quad = 10^{15} = 1 quadrillion Btu

Contents

Summary

Livestock and poultry wastes could become a $1.08-billion energy source for farms in 12 Southern States by 1990 if conventional energy prices continue to increase, according to this study of biomass energy conversion. Energy from this region represents 31 percent of the total potential value of biomass-based energy recoverable from livestock and poultry manure in the United States in 1990. Biomass refers to organic matter directly burned or anaerobically converted to methane gas to produce thermal or electrical energy.

More than 79.5 trillion Btu (British thermal units) of energy could be economically recovered from manure and litter in 1990, enough energy to heat hot water for 1.6 million homes for 1 year. Most livestock and poultry manure in the South is now spread on land as a fertilizer supplement, the value of which in 1990 would total only about $400 million, considerably less than half its potential value as a biomass energy source.

"Economically recoverable energy" from anaerobic digestion, as assessed in this study, comes from dairy herds of 30 cows or more, hog farms with sales of 500 head or more per year, grain-fed cattle on farms with sales of 1,000 head or more annually, and poultry farms with flocks of 20,000 hens or more. These farms could produce more than 20 billion cubic feet of methane gas in 1990, valued at $291 million if substituted for LP gas.

Thermal energy from direct burning of poultry litter wastes is derived from broiler farms with sales of 60,000 birds or more annually, turkey farms with yearly sales of 30,000 birds or more, and pullet growing farms with annual sales of 30,000 birds or more. Energy from these sources could be worth almost $789 million in 1990 if that energy were substituted for LP gas.

Energy from the methane gas or direct burning will have the highest value uses identified in the study when substituted for LP gas, and their combined values could reach $1.08 billion.

Study estimates were based on 1980 levels of manure residues on farms which could economically install conversion processes such as anaerobic digestion to produce methane or direct burning. Anaerobic digestion involves production of methane gas from bacterial decomposition of organic matter in an airless chamber. Projections of energy amounts and values to 1985 and 1990 were adjusted for handling and conversion losses.

Some farms with anaerobic digesters could use methane to produce electricity. Others, directly burning poultry wastes, could substitute these wastes for low-priced softwood shavings. Such uses, considered the least valuable energy options by the study, would be valued at only $344 million in 1990, significantly less than the manure's value as a fertilizer supplement. Manure used as a feed supplement, now possible through modern feeding technology, would be worth much more than its fertilizer value but less than its highest valued energy use.

The major livestock and poultry producing States in the region are Arkansas, Georgia, North Carolina, and Alabama which account for about 64 percent of the thermal energy potential of the South. Broilers have 55.4 percent of the total energy potential, followed by dairy cows, 13.8 percent; laying hens, 10.4 percent; turkeys, 9.4 percent; hogs, 6.7 percent; pullets, 3.0 percent; and fed beef, 1.3 percent. Florida, South Carolina, Louisiana, Mississippi, Kentucky, Tennessee, Virginia, and West Virginia were the other States included in this study.

Energy Potential from Livestock and Poultry Wastes in the South

Harold B. Jones, Jr., and E. A. Ogden*

Introduction

Biomass energy derived from organic matter is a major alternative energy source. Annual potential for biomass energy in the United States could range from 7 to 16 quadrillion Btu (quads) by the year 2000 [*32*].[1] This amount of energy is equivalent to about 9 to 20 percent of the estimated total U.S. energy consumption of 78 quads in 1980.

Wood is by far the largest single source of biomass energy, expected to provide 5 to 10 quads by the year 2000 (table 1). Forage crops and municipal solid wastes are next in importance with energy potentials ranging from 1 to 5 quads annually. Grains, crop residues, food processing wastes, and animal wastes will each contribute 1 quad or less to the energy potential in the year 2000.

About 0.27 quad of energy could be produced annually in the United States if all animal manure in confined livestock operations were converted to fuels by anaerobic digestion [*25*]. However, about 15 percent of this output would be needed to operate the digester systems, leaving a net output of 0.23 quad. The Southern States considered in this report could produce 0.079 quad of energy from anaerobically digested or burned poultry wastes at economic levels by 1990. Direct combustion rather than anaerobic digestion may be the most effective use for poultry wastes with large amounts of litter. Energy potential from livestock and poultry wastes will vary greatly by State and region, depending upon the nature and size of enterprises and manure-handling practices.

This study focuses on the economic potential for using farm wastes for biomass energy in 12 Southern States. Feasibility of converting such waste products into various fuels varies considerably by region depending upon the types and location of agricultural enterprises and the availability of alternative fuels.

Objectives

Objectives of the project were to: (1) determine the quantity and location of agricultural and food-related biomass that can be converted to energy fuels for individual States and regions; (2) estimate costs of collecting and converting biomass feedstocks and agricultural wastes into energy; (3) assess potential

Table 1—Potential sources of biomass energy in the United States by year 2000

Source	OTA [25]	DOE [42]	Purdue [34]	Purdue [33]
		Quadrillion Btu		
Grains	0.0-1	0.25	0.6-0.8	0.3-0.7
Crop residues	.8-1.2	—	.6-.9	.6-1.0
Wood	5.0-10	—	—	5.0-10
Forage crops	.0-5	—	1.0-2.3	1.0-4
Food wastes	.1	<.1	—	.0-.1
Animal wastes	.1-.3	—	—	.1-.3
Municipal solid wastes	—	.1	—	.2-.5
Total	—	—	—	7.0-16

— = Data not reported.

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[1]Italicized numbers in brackets refer to sources in Reference section.

economic, institutional, or environmental limitations for producing biomass fuels; and (4) determine relative use values and competitive positions of energy fuels from biomass energy sources.

This report focuses on one phase of the project: the potential for biomass energy from livestock and poultry wastes in the Southern United States. Three farm production subregions are considered: the Southeast, the Delta States, and the Appalachian region (fig. 1). Biomass energy estimates are presented for individual States, the subregions, and the region. Biomass energy potentials for other regions will be covered in separate reports.

Procedure

This study uses the following procedure:

(1) The quantity, location, and availability of animal and poultry manure were estimated by State for the base year 1980, 1985, and 1990 by compiling and projecting animal number trends and then applying manure output ratios to these numbers to get dry weight estimates of wastes available for energy use.

(2) These manure volumes were then converted to gross energy potentials based on technical conversion rates for methane gas production or direct-burning processes.

(3) An evaluation of previous studies on costs and economies of scale in methane generation and direct burning was undertaken to establish minimum-size livestock and poultry enterprises feasible for onsite energy conversion processes.

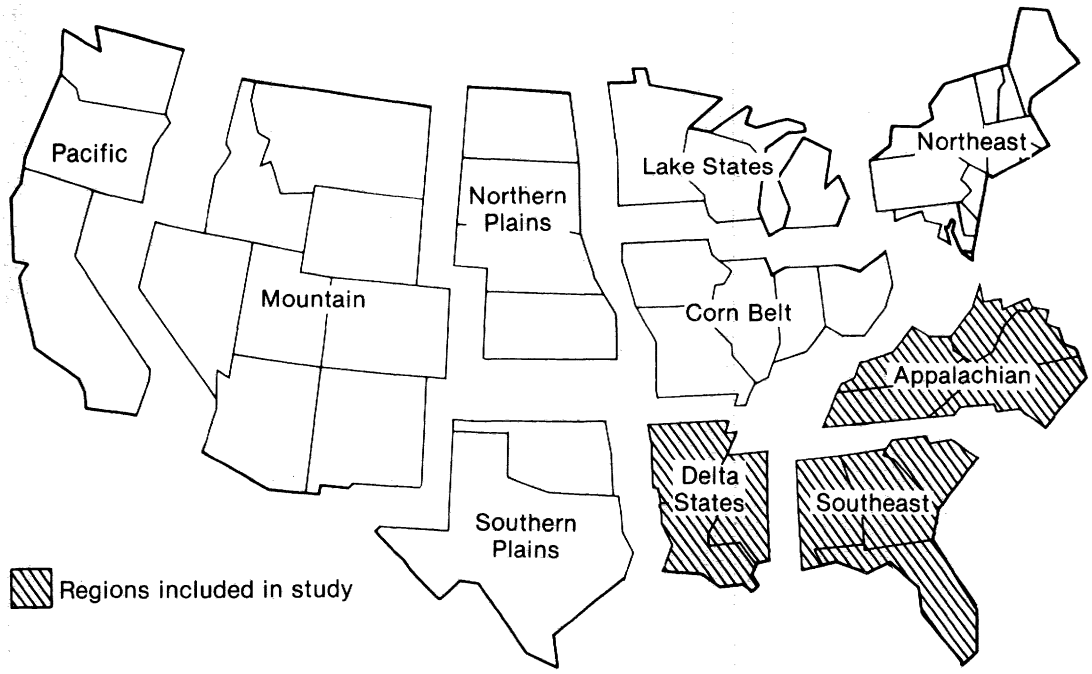
(4) Animal numbers and manure volume estimates were then adjusted to include only output from minimum-size farms or larger.

(5) These volumes were then converted to economically recoverable energy potentials after allowing for handling losses and conversion efficiency in the methane generation or direct-burning processes; electrical energy production potential was also included where appropriate.

(6) Energy values from biomass conversion of wastes were estimated based on conventional fuel prices and these values were then compared with alternative use values as fertilizer and animal feed, providing a rough estimate of the relative competitive position of biomass energy from the farmers' standpoint.

Figure 1

Farm Production Regions



Trends and Location of Livestock and Poultry Production

Potential for biomass energy from livestock and poultry wastes depends greatly on size and location of farm enterprises, number of confined animals, and availability of manure residues for conversion to energy. Quantity and availability of residues also vary by type of livestock and farm operating practices. This section of the report describes trends and location of livestock and poultry in the South with projections to 1985 and 1990.

Dairy Cows

Dairy farm numbers in the United States have declined rapidly since the early fifties. Dairy cow numbers dropped from 17.5 million in 1960 to 10.8 million in 1980. Commercial-size farms with annual sales of $2,500 or more declined from 602,000 in 1950 to 205,000 farms in 1979 [*12*]. The average herd size more than doubled during this period, however, to about 53 cows per farm. U.S. milk production declined only slightly, due to greater productivity per cow. Regional shares of milk production remained about the same between 1960 and 1974, except for the Corn Belt, which showed a decrease in production (from 18 to 14 percent of the U.S. total), and the Southwest, which increased production from 8 to 11 percent of the U.S. total. Most of the regional shifts in production are attributed to population increases and changes in comparative advantage or relative costs of production. Some large-scale drylot operations with herds of 2,000 to 10,000 cows have also been established in California, Arizona, and Florida. The trend toward large herds is expected to continue.

Dairy cow numbers in the Southeast, Delta, and Appalachian regions declined faster than the U.S. rate in the last two decades [*37*]. Their share of U.S. production dropped from 19.4 percent in 1960 to 14 percent in 1980-81. However, the downtrend seems to be leveling off; projected decreases in dairy cow numbers are likely to be close to the U.S. average in the eighties. The annual decline in U.S. cow numbers is expected to be about 1 percent or less in the eighties [*3*], resulting in an 8-percent decline by 1990. Most States in the South will show small declines in cow numbers, but some will probably maintain herds at current levels. Southern cow numbers are projected to drop 5 percent between 1980 and 1990 (see table 3).

Dairy cows in the South are most numerous in Kentucky, Tennessee, Florida, and Virginia [*37*]. However, cows are generally widespread throughout the region with concentrations in northwestern Louisiana, north-central Georgia, central Florida, and the eastern border of Tennessee [*39*]. Farms with herds of 100 cows of more show a similar geographic pattern. Herd sizes within the region are generally similar to the U.S. average, with 84 percent of the cows found in herds of 30 cows or more [*39*]. Larger herds are more common in Louisiana, Florida, Georgia, and South Carolina, however, with 93 percent or more of the cows in these States in herds of 30 cows or more. The most common herd sizes in most States range from 50 to 200 head with nearly half of the dairy cows in the region in this category.

Hogs and Pigs

The number of U.S. hog producers declined rapidly from 1.4 million in 1954 to 400,000 in 1979 [*44*]. This decline can be attributed to improved technology and a decrease in small farm-based enterprises. Hog production has become a more intensive, highly specialized enterprise with many large-scale production units. The number of hogs produced, however, has remained about the same over the years given the normal cyclical trends [*37*]. Hog production peaked in 1970 and again in 1979 at just over 100 million head. Pork production could increase 38 percent between 1980 and 2000 given a 20-percent growth in U.S. population [*18*]. Other estimates are somewhat lower [*44*]. With a trend toward heavier hogs, the number of hogs produced will not increase at the same rate as pork production. Farrowings would have to increase from 13.5 million in 1980 to 14.4 million in 1990 to provide 65 pounds of pork per person, given the expected level of population growth [*7*]. This would mean a 6.7-percent increase in the number of hogs by 1990.

Hog production has been concentrated in the Corn Belt, with 66 percent of total U.S. production occurring there in 1975 [*44*]. Other regions have shown little change in share of production except for the Northern Plains, which increased slightly from 10.4

to 12.8 percent of the U.S. total between 1950 and 1975. The South also increased its share of production slightly from 16.9 percent in 1960 to 17.5 percent in 1980 [*37*]. This trend is expected to continue with increases in hog numbers in the South projected to be somewhat greater than the U.S. average between 1980 and 1990 (see table 4). The largest increases are projected for Arkansas, Virginia, North Carolina, and Georgia, all of which have increased production steadily in the last two decades. Breeder hogs are expected to increase at a somewhat slower rate than market hogs between 1980 and 1990 due to expected increases in productivity per sow.

Southern hog production is greatest in North Carolina and Georgia, although Kentucky and Tennessee also produce a large number. The greatest concentration of farms in the South is along the coastal sections of the Southeast, ranging from Virginia and North Carolina to southern Georgia and Alabama [*39*]. The majority of southern farms are small, but there are a number of large farms also, particularly in North Carolina and Georgia. Larger farms with annual sales of 500 hogs or more account for 50 percent of the production in the region, which is similar to the U.S. average (55 percent) [*39*]. States with a high proportion of hogs produced on large farms are North Carolina, Arkansas, Virginia, Georgia, and South Carolina, all of which produce more than 50 percent of their output from farms with 500 hogs or more.

Cattle on Feed

U.S. production of beef cattle has changed substantially in the last 30 years. Large increases in cattle feeding operations and development of large commercial feedlots have altered the structure of the industry and influenced traditional cattle production cycles [*21*]. Total cattle numbers peaked at 132 million head in 1975 and dropped to a low of 110.9 million in 1979 [*37*]. However, the number of cattle and calves on feed as of January 1 shows a different pattern. Their numbers increased from 7.6 million in 1960 to a high of 14.4 million in 1973 before declining somewhat in the late seventies [*37*]. There were 11.6 million cattle and calves on feed in 1981. Cattle on feed as a percentage of total cattle numbers have ranged between 8 and 12 percent; they were about 11 percent in 1980. Total cattle numbers are expected to peak again at 122 to 124 million head in the 1986 to 1988 period [*38*]. The number of cattle on feed will likely reach 13.8 million head by 1990, reflecting a 12-percent increase over 1980 production.

Cattle feeding operations are of two basic types: the traditional farmer feedlot and the large commercial feedlot. Large commercial feedlots with a capacity of 1,000 head or more have expanded rapidly in the last two decades [*21*]. This trend will likely continue due to the specialized nature of large feedlots and the economies of scale inherent in such operations.

The increase in feeding associated with large feedlots has altered regional locational patterns, with nearly all of the growth since 1955 occurring in the Southern Plains [*21*]. Corn Belt States have steadily lost their share of production in cattle feeding operations, declining from 40 percent of the U.S. total in the fifties to about 20 percent in the late seventies. The Southern Plains accounted for 44 percent of all fed cattle marketed in 1979 compared with 20 percent for the Corn Belt States. The Southeastern, Delta, and Appalachian States, in contrast to the Southern Plains region, account for less than 3 percent of cattle and calves on feed in the United States (see table 5). These States have shown very little change in cattle numbers on feed since the sixties. This situation is likely to remain the same in the eighties with the Southeastern, Delta, and Appalachian States' share of U.S. production continuing to be very small.

Southeastern cattle feeding operations are generally very small and the number of large commercial feedlots has recently declined. In 1978, there were 56 large feedlots selling 1,000 cattle or more annually which accounted for 28 percent of the total fed cattle sold in the region [*39*]. Most of these large feedlots were in Florida and Georgia, although there were a few large feeders scattered throughout the region. Smaller feeding operations with fewer than 1,000 cattle were most numerous; they accounted for 72 percent of the fed cattle sold in the region. This region is not likely to become a major cattle feeding area in the eighties.

Laying Hens

The number of egg producers in the United States has declined rapidly since the early sixties. The number of farms with hens and pullets of laying age dropped from 1.15 million in 1964 to 308,852 in 1978 [*39*]. Commercial-size flocks of 20,000 hens or more increased substantially, however, and now account for 72 percent of total production. The number of laying hens declined moderately from 295 million in 1960 to 288 million in 1980 [*37*], but total egg production continued to increase due to improved productivity per layer. Increases in egg production in the eighties are likely to be moderate with per capita consumption remaining stable or perhaps increasing only slightly [*27*]. Growth in consumption will be influenced mainly by population growth. Due to continued improvements in productivity of layers, the number of hens will probably continue to decline, but at a slower rate than in previous years.

Laying hen numbers in the South increased rapidly between the early fifties and the seventies, reflecting the substantial shift in egg production from the Midwest to the South [*27*]. In 1980, the South accounted for 37 percent of U.S. laying hens, up from 23 percent in 1960. However, hen numbers in the region increased the most in the Southeast and Delta States, whereas they showed a consistent and substantial decline in the Appalachian region (except for North Carolina) [*37*]. Increases in the number of hens in most Southern States have stabilized since the early seventies, however. Only a 3-percent increase in hen numbers is projected for the eighties (see table 6).

Laying hens in the South are most numerous in Georgia and Arkansas, followed by Alabama, North Carolina, and Florida [*37*]. These States account for 75 percent of the hens in the South. The southern egg industry is characterized by high density production centers in most States, with large specialized production facilities. Average-size farms have increased greatly in recent years with a substantial number of eggs produced under contract. Flock sizes are generally similar to the U.S. average, with 67 percent of birds in flocks of 20,000 layers or more [*37*]. Large flocks predominate in all States except West Virginia. The most common flock size in most States ranges from 10,000 to 50,000 birds, but there are still a substantial number of farms in the region with flocks of fewer than 10,000 hens.

Broilers

U.S. broiler production expanded rapidly from 789 million birds in 1951 to 4.15 billion in 1981 [*37*]. The industry has become highly specialized with almost all of the production from vertically integrated firms contracting with growers. The number of growers increased very little, with 34,474 farms raising broilers in 1978 compared to 33,753 in 1969 [*39*]. The average-size broiler farm increased substantially during this period, however, with nearly 95 percent of the broilers in 1978 raised on farms with annual sales of 60,000 birds or more. Broiler production is expected to continue to increase in the eighties at about the same rate as in the seventies due to increased demand for poultry meat from a growing population and improved technology making the industry more competitive [*18, 27*]. Projected levels of production may approach 5.3 billion birds by 1990.

Broiler production has been concentrated in the South Atlantic and South Central regions which accounted for 89 percent of U.S. output throughout the seventies [*15*]. The Southeast, Delta, and Appalachian States accounted for 72 percent of broiler production in 1981 [*37*]. Production in the South has increased substantially over the years from 1.13 billion birds in 1960 to 3 billion birds in 1981. The region's share of production has also continued to increase since the early fifties. Output of broilers is likely to continue to increase in these States at about the same rate as in the seventies. By 1990, production in the region could approach 3.8 billion birds (see table 7).

Southern broiler production is most concentrated in Arkansas, Georgia, Alabama, and North Carolina, but large production centers are also located in Mississippi and Virginia and certain sections of other States [*39*]. Increased levels of production are expected to continue in all States except Kentucky. Production facilities in the region are highly specialized and flock sizes are expected to increase as growers continue to expand and upgrade buildings and equipment. Farm sizes are almost identical to the U.S. average, with 95 percent of the broilers produced on farms with annual sales of 60,000 birds or more [*39*]. Farms with sales of 100,000 broilers or

more accounted for 80 percent of production within the region in 1978. Kentucky and Tennessee are the only States in the region with relatively small farms.

Turkeys

U.S. turkey production grew rapidly from 60 million birds in 1953 to 170 million in 1981 [*37*]. The industry has changed greatly, with fewer small farm flocks and an increasing number of large-scale, vertically integrated operations contracting with growers [*27*]. Seasonality of production has declined and there has been a trend toward more confinement rearing. These changes have resulted in a substantial decline in number of farms producing turkeys and an increase in flock sizes. Commercial-size farms with annual sales of 30,000 turkeys or more accounted for 87 percent of U.S. production in 1978 [*39*]. Turkey production is expected to continue to increase in the eighties at a rate similar to the seventies due to increasing demand for turkey products, a growing population, and improved efficiency in production [*27*]. The number of birds produced could approach 234 million by 1990.

Turkey production has been heavily concentrated in the Midwest, but this region's share of production has slowly declined since the late fifties [*15*]. In 1980, the Midwest accounted for 38 percent of U.S. turkey production, compared with 50 percent in 1959. Turkey production grew most rapidly in the South during this period, with most of the increase occurring in the South Atlantic region. The Southeast, Delta, and Appalachian States increased production over fivefold between 1960 and 1981. These States now account for 35 percent of U.S. turkey production. Output of turkeys in the South will likely continue to increase at about the same rate as the U.S. average in the eighties. By 1990, regional production could surpass 84 million birds (see table 8).

Southern turkey production is greatest in North Carolina, Arkansas, and Virginia, three of the leading turkey producing States in the country [*37*]. These States produced 87 percent of the turkeys in the South in 1981 and 30 percent of U.S. production. Expansion of turkey production is expected to continue at a rapid rate in these States. Some other States in the region, notably Georgia, South Carolina, and West Virginia, have smaller numbers of turkeys, but they are also expanding rapidly. Turkey production is a concentrated industry located in high-density production areas within each State. There are few or no turkeys grown in Alabama, Florida, Louisiana, Mississippi, Kentucky, and Tennessee. Flock sizes are similar to the U.S. average with most of the turkeys produced on farms with annual sales of 30,000 birds or more [*39*].

Pullets

Pullet production is closely related to the number of laying hens on farms since pullets are primarily grown as replacements for egg producers. The number of hens and pullets of laying age in the United States has declined moderately since the sixties, and pullets of nonlaying age have also declined [*37*]. Decreases in pullet production have been somewhat greater than decreases in number of laying hens, however, due to the improved performance of layers and the rapid development of forced-molting practices. The ratio of nonlaying pullets to laying hens declined from 33.1 in 1970 to 31.8 in 1980. Further declines in pullet production are likely to be moderate, depending upon forced-molting practices. The number of nonlaying pullets on hand December 1 in the United States could approach 92 million birds by 1990 (173 million birds for the year).

Southern pullet production increased greatly since the early sixties, but there has been a gradual decline in numbers produced since 1970. This decline has not been as rapid as in the United States as a whole, however. Production of pullets in the South is expected to remain relatively stable throughout the eighties and could be about 44 million birds in 1990 based on December 1 inventories (83 million birds total for the year).

Southern pullet production is most important in Arkansas, Georgia, Alabama, North Carolina, and Florida [*37*] (see table 9). These five States account for 77 percent of the birds in the region, which closely parallels laying hen production patterns. Very few birds are produced in Kentucky, West Virginia, and Louisiana. Production centers in most States are similar to those for laying hens, reflecting high-density, specialized production facilities. Average flock sizes have increased greatly in re-

cent years, with 73 percent of the pullets produced on farms with annual sales of 30,000 birds or more [*39*]. Flock sizes are generally large in all States except West Virginia, although there are still many producers with sales of 8,000 to 30,000 birds.

Gross Potential Energy Content of Manure and Litter

Organic matter can be converted to various forms of energy by a number of technical processes, depending upon the raw material characteristics and the type of energy desired. These processes include: (1) direct combustion of certain products such as wood, (2) thermochemical conversion of materials to liquid fuels such as wood alcohol, (3) thermochemical gasification for production of synthetic gas from wood or agricultural residues, (4) production of ethanol by fermentation, and (5) production of methane gas by anaerobic digestion [*41*]. The technical and economic feasibility of these processes is highly variable, and not all of them have proven to be financially sound or commercially available.

Anaerobic digestion is probably the most feasible process for converting manure feedstocks into energy [*25*]. Manure is generally suitable for the digestive process, and many livestock and poultry enterprises with confined housing and feeding systems can provide the manure volume needed to make anaerobic digestion possible. Anaerobic digestion is also well developed from a technical standpoint and commercial-scale operations are available for larger operations. Poultry operations with large quantities of litter are not as suitable for anaerobic digestion, however, due to the lignin-cellulose content of the waste affecting the efficiency of the digestive process. Direct combustion is probably the most feasible process for converting litter-based manure into energy.

Anaerobic Digestion Process

Anaerobic digestion is a relatively efficient conversion process producing medium-Btu gas from biochemical processes [*41*]. A natural decomposition process used successfully for many years in the treatment of organic wastes, anaerobic digestion involves production of methane gas from the bacterial decomposition of organic matter in a chamber devoid of air. Used extensively in India and China for generating biogas from animal and human wastes, anaerobic digestion in the United States has been used to treat municipal wastewater. With recently rising conventional energy prices, anaerobic digestion has been used more frequently on farms to produce biogas from manure.

Anaerobic digestion involves the care and feeding of methanogenic, anaerobic microorganisms in a controlled environment. Large airtight vessels called digesters are fed a slurry of animal wastes of certain consistency at specific time intervals. They are then held at a certain temperature for specified time periods. The nature and composition of the wastes determine the loading rate, temperature, and retention time of the system. Most systems are site-specific with these variables being determined for each operation. The microorganisms digest the wastes, producing a mixture of methane, carbon dioxide, and other trace gases. The process is applicable to livestock operations with sufficient volume to supply minimum amounts of manure required for a given size system. There are some commercially designed systems available, but they are primarily for large-scale operations [*13, 25*]. However, it is possible to design custom systems for smaller farm operations; these are being developed experimentally at various universities and also commercially [*11, 14*].

Anaerobic digestion produces a collectable biogas with an average methane content of 60 percent plus a digested sludge which can be used as a soil fertilizer or livestock feed ingredient. Because of pretreatment procedures required for the manure, a mechanical waste management system is necessary to feed the digester and handle its byproducts. Therefore, farms with organized manure handling systems, such as liquid slurries, are more adaptable for anaerobic digestion. The methane produced by the system could be used as a heating fuel for boilers or substituted for natural gas, fuel oil, or LP gas (liquid petroleum gas) on the farm. In larger operations, the gas could be scrubbed to remove impurities and compressed for sale as synthetic natural gas to pipeline companies. The gas could also be used to power engines to generate electricity for onfarm operations or perhaps sold to electric utilities. Methane gas is generally not practical as a mobile fuel due to the pressure needed to keep it in liquid form. Due to the high cost of compression, methane is very expensive to store.

Capital investment required for an anaerobic digester is relatively low compared to other forms of biomass energy conversion [*41*], but these costs can be relatively high for individual farms depending upon the size of the system and the nature of the manure handling process. Large-scale, commercially built digesters, such as those used by large cattle feeding operations of 10,000 head or more, could cost $1- to $2 million or more [*13, 41*]. Smaller farm digesters could be built for less than $100,000, depending upon size and type of system. Some very small digesters have been built for less than $50,000; they may be suitable for small dairy, swine, or poultry farms [*11, 14*]. Capital costs are highly variable, however, depending upon system design factors and availability of farm labor for construction. Anaerobic digesters can also be technologically cumbersome for some farmers to operate on a part-time basis, especially if they lack experience in this type of process.

Direct Combustion Process

Direct combustion of litter-based poultry manure will probably be more advantageous than anaerobic digestion due to lower capital investment costs and the irregular supplies of litter available from poultry houses cleaned out only once or twice a year. Methane gas could be produced in quantity from litter, but the economics of the conversion process is only marginal at best [*30*]. Also, the even flow of energy from anaerobic digester systems does not fit the specific energy needs of poultry growers where the brooding process requires extensive heat primarily during the first 2 weeks of the growing stage. The direct combustion process is also more flexible in terms of feedstock storage possibilities and for meeting seasonal or cyclical burning needs for functions other than brooding.

Direct combustion of poultry litter is similar to burning wood chips or other wood residues. The moisture content of litter ranges from 25 to 35 percent. Litter could be burned directly or transformed into pellets for easier storage and handling and more efficient burning [*25, 30*]. Energy values from burning litter are relatively high and capital investment costs for furnace or boiler facilities are relatively low for small operations. Small wood-fired, warm air heating systems for broiler houses can be constructed for less than $18,000 and possibly as low as $8,800 depending on the type of system needed [*24*]. However, larger steam boilers using wood fuels would cost $500,000 or more depending upon the size and type of boiler system required [*43*]. Wood burning systems, however, have lower capital investment costs per Btu than anaerobic digestion systems even though operating costs may be somewhat higher.

Gross Energy Potential for the South

The gross energy potential from livestock and poultry wastes in the South was based on manure output from all animals and birds on farms for the base year 1980 with projections for 1985 and 1990. Estimates of manure produced were based on manure residue rates for each species on a dry weight basis (table 2). These rates vary greatly by species, but they are related to the feed input of the animal. The volume of manure produced by the various species was then converted to the maximum possible potential energy based on theoretical benchmark coefficients for either anaerobic digestion or direct combustion [*14*]. Electrical energy potential was also calculated for wastes from those species with manure treatable by anaerobic digestion.

Dairy Cows. Dairy cows produce an average of 1.95 tons of manure per cow annually which could result in a total manure volume of 2.82 million tons for the South in 1990 (table 3). The theoretical maximum biogas production potential from anaerobic digestion of this manure without losses would be 10.6 cubic feet per pound of dry weight or 13.3 cubic

Table 2—Manure residue rates and production periods for various livestock and poultry species, southern region, 1982

Species	Animal units	Manure residue rates	Production period	Sources
	Number	*Tons, dry wt.*	*Weeks*	*Reference*
Dairy cows	1	1.95	52	[*6, 14, 45*]
Swine	1	.07	26	[*6, 14, 45*]
Fed beef	1	.62	26	[*6, 14, 45*]
Laying hens	1,000	12.60	52	[*9, 20, 31, 45*]
Broilers	1,000	1.25	8	[*23, 26, 31, 45*]
Turkeys	1,000	12.60	20	[*9, 31, 45*]
Pullets	1,000	3.00	22	[*31, 45*]

Table 3—Dairy cows: Animal numbers and gross potential volume and energy content of manure with anaerobic digestion

Region and State	Dairy cows[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 head			*1,000 tons dry weight*			*Billion cubic feet*			*Billion Btu*			*gWh*		
Southeast:															
Alabama	68	63	61	133	123	119	2.8	2.6	2.5	1,680	1,560	1,500	491.9	456.8	439.2
Florida	187	185	183	365	361	357	7.7	7.7	7.6	4,620	4,620	4,560	1,352.7	1,352.7	1,335.2
Georgia	130	130	130	254	254	254	5.4	5.4	5.4	3,240	3,240	3,240	948.7	948.7	948.7
South Carolina	48	45	43	94	88	84	2.0	1.9	1.8	1,200	1,140	1,080	351.4	333.8	316.2
Total[6]	433	423	417	844	825	813	17.9	17.5	17.2	10,740	10,500	10,320	3,144.7	3,074.4	3,021.7
Delta States:															
Arkansas	81	79	77	158	154	150	3.3	3.3	3.2	1,980	1.980	1,920	579.7	579.7	562.2
Louisiana	114	107	103	222	209	201	4.7	4.4	4.3	2,820	2,640	2,580	825.7	773.0	755.4
Mississippi	98	93	88	191	181	172	4.0	3.8	3.6	2,400	2,280	2,160	702.7	667.6	632.4
Total[6]	293	279	268	571	544	523	12.1	11.5	11.1	7,260	6,900	6,660	2,125.7	2,020.3	1,950.0
Appalachian:															
Kentucky	242	230	218	472	449	425	10.0	9.5	9.0	6,000	5,700	5,400	1,756.8	1,669.0	1,581.1
North Carolina	134	128	121	261	250	236	5.5	5.3	5.0	3,300	3,180	3,000	966.2	931.1	878.4
Tennessee	214	214	214	417	417	417	8.8	8.8	8.8	5,280	5,280	5,280	1,546.0	1,546.0	1,546.0
Virginia	172	172	172	335	335	335	7.1	7.1	7.1	4,260	4,260	4,260	1,247.3	1,247.3	1,247.3
West Virginia	37	37	37	72	72	72	1.5	1.5	1.5	900	900	900	263.5	263.5	263.5
Total[6]	799	781	762	1,558	1,523	1,486	33.0	32.3	31.5	19,800	19,380	18,900	5,797.4	5,674.5	5,533.9
Regional total	1,525	1,483	1,447	2,974	2,892	2,822	63.0	61.3	59.8	37,800	36,780	35,880	11,067.8	10,769.2	10,505.7
U.S. total	10,815	10,383	9,950	21,089	20,247	19,403	447.1	429.2	411.3	268.260	257,520	246,780	78,546.5	75,401.9	72,257.2
Regional total as percentage of U.S. total							*Percent*								
	14.1	14.3	14.5	14.1	14.3	14.5	14.1	14.3	14.5	14.1	14.3	14.5	14.1	14.3	14.5

[1]Data from [*37*]. Projections based on trend extrapolations from 1980 base year. Figures include average number of milk cows on farms during year.

[2]Based on 1.95 tons of manure produced per cow, dry weight basis [*6, 22, 45*].

[3]Based on 10.6 cubic feet of biogas per pound of manure, dry weight. Volatile solids are 80 percent of total solids (dry weight) and yield 13.3 cubic feet of biogas per pound [*14*].

[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].

[5]Based on $2.928 = 10^{-4}$ kWh per Btu, or 3,415.3 Btu per kWh [*22*].

[6]Columns may not total due to rounding.

feet per pound of volatile solids (with volatile solids 80 percent of dry weight).

Biogas production potential for the region is 59.8 billion cubic feet in 1990. Biogas consists of approximately 60-percent methane gas plus 40-percent carbon dioxide and other gas impurities, with the methane gas having an energy content of about 1,000 Btu per cubic foot. The methane gas can be used for direct burning on the farm or it can be converted to electricity by an engine-generator system. Methane gas burned directly could produce 35.9 trillion Btu of energy in the region in 1990. If methane gas were used to generate electricity, it could produce more than 10,500 gigawatthours in 1990. Energy potential from dairy cows in the South was 14.1 percent of the total U.S. energy potential from dairy cow wastes in 1980, and was projected to 14.5 percent in 1990.

Hogs and Pigs. Hogs produce about 0.07 ton of manure per animal on a dry weight basis during their 26-week production period. This could result in a total hog manure volume of 1.52 million tons in 1990 in the South (table 4). Maximum biogas production from this manure at 100-percent anaerobic digestion efficiency would be 10.6 cubic feet per pound of dry weight or 13.3 cubic feet per pound of volatile solids (with volatile solids 80 percent of dry weight).

Biogas production potential for the region would be 32.2 billion cubic feet in 1990. Methane from this process burned directly on the farm would produce thermal energy amounting to 19.3 trillion Btu in the South in 1990. Used to generate electricity, the methane gas' potential energy output would be almost 5,700 gigawatthours in the South in 1990. The energy potential from hogs in the South was 17.5 percent of the total U.S. energy potential from hog wastes in 1980, and was projected to be 18.4 percent in 1990.

Cattle on Feed. Fed cattle, normally confined in feedlots of some type, produce about 0.62 ton of manure per animal on a dry weight basis during the fattening period of about 26 weeks. This could produce a total manure volume in the South of 473,000 tons in 1990 (table 5). With an anaerobic digestion system, the maximum biogas production potential from this manure at 100-percent efficiency would be 10.6 cubic feet per pound of dry weight or 13.3 cubic feet per pound of volatile solids (with volatile solids 80 percent of dry weight).

The biogas production potential for the region would be 10 billion cubic feet in 1990. Methane gas from this process burned directly on the farm would produce thermal energy totaling 6 trillion Btu in the region in 1990. Used to generate electricity, methane gas would have a potential energy output of nearly 1,760 gigawatthours in 1990. Energy potential from cattle on feed in the South is small, accounting for only about 2.5 percent of the total U.S. energy potential from fed cattle manure in 1980 through 1990.

Laying Hens. Laying hens produce approximately 12.6 tons of manure per 1,000 birds annually on a dry weight basis which could result in a total manure volume of 1.38 million tons in 1990 (table 6). With an anaerobic digestion system, the maximum biogas production potential from this manure at 100-percent efficiency would be 9.7 cubic feet per pound of dry weight or 13.3 cubic feet per pound of volatile solids (with volatile solids 73 percent of dry weight).

Biogas production potential for the region would be an estimated 26.8 billion cubic feet in 1990. Burning this methane gas on the farm would produce thermal energy amounting to 16.1 trillion Btu in 1990. Used to generate electricity, the methane gas potential energy output would be almost 4,710 gigawatthours in the region in 1990. The energy potential from laying hens in the South is projected to be 39.3 percent of the total U.S. energy potential from laying hen wastes in 1990.

Broilers. Broilers produce about 1.25 tons of manure per 1,000 birds on a dry weight basis during their 8-week production cycle. This could produce a total manure volume of 4.72 million tons in the South in 1990 (table 7).

Direct combustion of broiler litter and manure will yield approximately 11 million Btu per ton dry weight. Burning the litter for heating would therefore provide almost 52 trillion Btu of energy in the South in 1990, nearly 72 percent of total U.S. energy potential from broiler wastes in that year.

Table 4—Swine: Animal numbers and gross potential volume and energy content of manure with anaerobic digestion

Region and State	Hogs and breeder hogs[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 head			*1,000 tons dry weight*			*Billion cubic feet*			*Billion Btu*			*gWh*		
Southeast:															
Alabama	1,554	1,593	1,632	109	112	114	2.3	2.4	2.4	1,380	1,440	1,440	404.1	421.6	421.6
Florida	741	778	815	52	54	57	1.1	1.1	1.2	660	660	720	193.3	193.3	210.8
Georgia	3,391	3,490	3,688	237	244	258	5.0	5.2	5.5	3,000	3,120	3,300	878.4	913.5	966.2
South Carolina	1,054	1,104	1,144	74	77	80	1.6	1.6	1.7	960	960	1,020	281.1	281.1	298.7
Total[6]	6,740	6,965	7,279	472	488	510	10.0	10.3	10.8	6,000	6,180	6,480	1,756.8	1,809.5	1,897.3
Delta States:															
Arkansas	1,346	1,547	1,749	94	108	122	2.0	2.3	2.6	1,200	1,380	1,560	351.4	404.1	456.8
Louisiana	228	216	205	16	15	14	.3	.3	.3	180	180	180	52.7	52.7	52.7
Mississippi	635	651	667	44	46	47	.9	1.0	1.0	540	600	600	158.1	175.7	175.7
Total[6]	2,209	2,414	2,621	155	169	183	3.2	3.6	3.9	1,920	2,160	2,340	562.2	632.5	685.2
Appalachian:															
Kentucky	2,282	2,339	2,396	160	164	168	3.4	3.5	3.6	2,040	2,100	2,160	597.3	614.9	632.4
North Carolina	4,427	4,773	5,117	310	334	358	6.6	7.1	7.6	3,960	4,260	4,560	1,159.5	1,247.3	1,335.2
Tennessee	2,306	2,421	2,536	161	169	178	3.4	3.6	3.8	2,040	2,160	2,280	597.3	632.4	667.6
Virginia	1,349	1,484	1,618	94	104	113	2.0	2.2	2.4	1,200	1,320	1,440	351.4	386.5	421.6
West Virginia	124	127	129	9	9	9	.2	.2	.2	120	120	120	35.1	35.1	35.1
Total[6]	10,488	11,144	11,796	734	780	826	15.6	16.5	17.5	9,360	9,900	10,500	2,740.6	2,898.7	3,074.4
Regional total	19,437	20,523	21,696	1,361	1,437	1,519	28.9	30.5	32.2	17,340	18,300	19,320	5,077.2	5,358.2	5,656.9
U.S. total	110,877	114,512	118,147	7,761	8,016	8,270	164.5	169.9	175.3	98,700	101,940	105,180	28,899.4	29,848.0	30,796.7
Regional total as percentage of U.S. total							*Percent*								
	17.5	17.9	18.4	17.5	17.9	18.4	17.5	17.9	18.4	17.5	17.9	18.4	17.6	17.9	18.4

[1]Data from [*37*]. Projections based on trend extrapolations from 1980 base year. Includes annual pig crop production plus breeder hogs.
[2]Based on 0.07 ton of manure produced per animal, dry weight basis [*6, 22, 45*].
[3]Based on 10.6 cubic feet of biogas per pound of manure, dry weight basis. Volatile solids are 80 percent of total solids (dry weight) and yield 13.3 cubic feet of biogas per pound [*14*].
[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].
[5]Based on 2.928×10^{-4} kWh per Btu, or 3,415.3 Btu per kWh [*22*].
[6]Columns may not total due to rounding.

Table 5—Cattle on feed: Animal numbers and gross potential volume and energy content of manure with anaerobic digestion

Region and State	Fed beef[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 head			*1,000 tons dry weight*			*Billion cubic feet*			*Billion Btu*			*gWh*		
Southeast:															
Alabama	68	83	83	42	51	51	0.9	1.1	1.1	540	660	660	158.1	193.2	193.2
Florida	120	118	120	74	73	74	1.6	1.5	1.6	960	900	960	281.1	263.5	281.1
Georgia	75	74	75	47	46	47	1.0	1.0	1.0	600	600	600	175.7	175.7	175.7
South Carolina	35	35	35	22	22	22	.5	.5	.5	300	300	300	87.8	87.8	87.8
Total[6]	298	310	313	185	192	194	4.0	4.1	4.2	2,400	2,460	2,520	702.7	720.2	737.8
Delta States:															
Arkansas	25	38	38	16	24	24	.3	.5	.5	180	300	300	52.7	87.8	87.8
Louisiana	17	17	17	11	11	11	.2	.2	.2	120	120	120	35.1	35.1	35.1
Mississippi	48	32	48	30	20	30	.6	.4	.6	360	240	360	105.4	70.3	105.4
Total	90	87	103	57	55	65	1.1	1.1	1.3	660	660	780	193.2	193.2	228.3
Appalachian:															
Kentucky	87	116	116	54	72	72	1.1	1.5	1.5	660	900	900	193.2	263.5	263.5
North Carolina	39	39	39	24	24	24	.5	.5	.5	300	300	300	87.8	87.8	87.8
Tennessee	65	86	86	40	53	53	.8	1.1	1.1	480	660	660	140.5	193.2	193.2
Virginia	85	77	85	53	48	53	1.1	1.0	1.1	660	600	660	193.2	175.7	193.2
West Virginia	20	16	20	12	10	12	.3	.2	.3	180	120	180	52.7	35.1	52.7
Total	296	334	346	183	207	214	3.8	4.3	4.5	2,280	2,580	2,700	667.4	755.3	790.4
Regional total	684	731	762	425	454	473	8.9	9.5	10.0	5,340	5,700	6,000	1,563.3	1,669.7	1,756.5
U.S. total	26,891	28,571	30,252	16,672	17,714	18,756	353.4	375.5	397.6	212,040	225,300	238,560	62,085.3	65,967.9	69,850.4
Regional total as percentage of U.S. total							*Percent*								
	2.5	2.6	2.5	2.5	2.6	2.5	2.5	2.5	2.6	2.5	2.5	2.5	2.5	2.5	2.5

[1]Data from [*37*]. Cattle and calves on feed on Jan. 1 adjusted to reflect total animals fed annually based on sales-inventory ratios from 1978 Census [*39*]. Projections based on trend extrapolations from 1980–81 base years.

[2]Based on 0.62 ton of manure per animal, dry weight basis [*6, 22, 45*].

[3]Based on 10.6 cubic feet of biogas per pound of manure, dry weight basis. Volatile solids are 80 percent of total solids (dry weight) and yield 13.3 cubic feet of biogas per pound [*14*].

[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].

[5]Based on 2.928×10^{-4}kWh per Btu, or 3,415.3 Btu per kWh [*22*].

Table 6—Laying hens: Number of birds and gross potential volume and energy content of manure with anaerobic digestion

Region and State	Laying hens[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	Million birds			*1,000 tons dry weight*			*Billion cubic feet*			*Billion Btu*			*gWh*		
Southeast:															
Alabama	13.7	14.5	15.2	173	183	192	3.4	3.6	3.7	2,040	2,160	2,200	597.3	632.4	.644.2
Florida	12.8	13.4	14.1	161	169	178	3.1	3.3	3.5	1,860	1,980	2,100	544.6	579.7	614.9
Georgia	23.2	22.3	21.4	292	281	270	5.7	5.5	5.2	3,420	3,300	3,120	1,001.4	966.2	913.5
South Carolina	6.8	7.1	7.5	86	89	95	1.7	1.7	1.8	1,020	1,020	1,080	298.7	298.7	316.2
Total[6]	56.5	57.3	58.2	712	722	733	13.8	14.0	14.2	8,280	8,400	8,520	2,424.4	2,459.5	2,494.7
Delta States:															
Arkansas	17.2	17.9	18.7	217	226	236	4.2	4.4	4.6	2,520	2,640	2.760	737.9	773.0	808.1
Louisiana	2.5	2.4	2.3	32	30	29	.6	.6	.6	360	360	360	105.4	105.4	105.4
Mississippi	6.6	6.0	5.3	83	76	67	1.6	1.5	1.3	960	900	780	281.1	263.5	228.4
Total[6]	26.3	26.3	26.3	331	331	331	6.4	6.4	6.4	3,840	3,840	3,840	1,124.4	1,124.4	1,124.4
Appalachian:															
Kentucky	2.3	2.3	2.2	29	29	29	.6	.6	.6	360	360	360	105.4	105.4	105.4
North Carolina	13.2	13.9	14.5	166	175	183	3.2	3.4	3.6	1,920	2,040	2,160	562.2	597.3	632.4
Tennessee	4.0	3.9	3.8	50	49	48	1.0	1.0	.9	600	600	540	175.7	175.7	158.1
Virginia	3.9	4.0	4.1	49	50	52	1.0	1.0	1.0	600	600	600	175.7	175.7	175.7
West Virginia	.6	.6	.6	8	8	8	.2	.2	.2	120	120	120	35.1	35.1	35.1
Total[6]	24.0	24.7	25.2	302	311	318	5.9	6.0	6.2	3,540	3,600	3,720	1,036.5	1,054.1	1,089.2
Regional total	106.8	108.3	109.7	1,346	1,365	1,382	26.1	26.5	26.8	15,660	15,900	16,080	4,585.2	4,655.5	4,708.2
U.S. total	287.8	283.5	279.1	3,626	3,572	3,517	70.3	69.3	68.2	42,180	41,580	40,920	12,350.3	12,174.6	11,981.4
Regional total as percentage of U.S. total							*Percent*								
	37.1	38.2	39.3	37.1	38.2	39.3	37.1	38.2	39.3	37.1	38.2	39.3	37.1	38.2	39.3

[1]Data from [*37*]. Projections based on trend extrapolations from 1980 base year. Figures include average number of hens and pullets of laying age on farms.
[2]Based on 12.6 tons of manure produced per 1,000 birds, dry weight basis [*9, 20, 31, 45*].
[3]Based on 9.7 cubic feet of biogas produced per pound of manure, dry weight. Volatile solids are 73 percent of total solids (dry weight) and yield 13.3 cubic feet of biogas per pound [*14*].
[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].
[5]Based on 2.928×10^{-4} kWh per Btu, or 3,415.3 Btu per kWh [*22*].
[6]Columns may not total due to rounding.

Turkeys. Turkeys produce about 12.6 tons of manure per 1,000 birds on a dry weight basis during their 20-week production period. This would result in a total manure volume estimated at 1.06 million tons in the South in 1990 (table 8). Direct combustion of turkey litter and manure will yield about 12 million Btu per ton dry weight. Litter burned on the farm would, therefore, provide 12.71 trillion Btu of energy in the South in 1990. This level represents nearly 36 percent of the total U.S. energy potential from turkey wastes in 1990.

Pullets. Pullets produce about 3 tons of manure per 1,000 birds on a dry weight basis during their 22-week growing period before being moved to layer flocks. This could result in a total manure volume of 248,000 tons in the South in 1990 (table 9). Pullet litter and manure will yield about 11 million Btu per ton dry weight if directly burned. Litter burned on the farm would, therefore, provide a thermal energy content estimated at 2.73 trillion Btu in the South in 1990, representing almost 48 percent of total U.S. energy potential from pullet wastes in 1990.

Economically Recoverable Energy from Manure and Litter

Biomass materials for fuels are highly site-specific since they are relatively bulky and have a low fuel value per pound compared with conventional fuels [*25*]. Because of this bulkiness and perishability, transportation costs for collecting and moving materials such as manure and litter to central pro-

Table 7—Broilers: Number produced and gross potential volume and energy content of litter and manure

Region and State	Broilers[1]			Manure volume[2]			Thermal energy content[3]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
	Million birds			*Tons dry weight*			*Billion Btu*		
Southeast:									
Alabama	494.7	573.9	653.0	618,375	717,375	816,250	6,802.1	7,891.1	8,978.8
Florida	87.1	105.9	124.6	108,875	132,375	155,750	1,197.6	1,456.1	1,713.3
Georgia	573.9	648.5	723.1	717,375	810,625	903,875	7,891.1	8,916.9	9,942.6
South Carolina	43.1	49.6	56.1	53,875	62,000	70,125	592.6	682.0	771.4
Total[4]	1,198.8	1,377.9	1,556.8	1,498,500	1,722,375	1,946,000	16,483.5	18,946.1	21,406.0
Delta States:									
Arkansas	634.9	765.0	895.2	793,625	956,250	1,119,000	8,729.9	10,518.8	12,309.0
Louisiana	99.0	122.2	145.5	123,750	152,750	181,875	1,361.3	1,680.3	2,000.6
Mississippi	276.0	321.5	367.1	345,000	401,875	458,875	3,795.0	4,420.6	5,047.6
Total[4]	1,009.9	1,208.7	1,407.8	1,262,375	1,510,875	1,759,750	13,886.1	16,619.6	19,357.3
Appalachian:									
Kentucky	3.2	3.2	3.2	4,000	4,000	4,000	44.0	44.0	44.0
North Carolina	399.6	457.5	515.5	499,500	571,875	644,375	5,494.5	6,290.6	7,088.1
Tennessee	66.9	74.6	82.3	83,625	93,250	102,875	919.9	1,025.8	1,131.6
Virginia	126.4	152.9	179.4	158,000	191,125	224,250	1,738.0	2,102.4	2,466.8
West Virginia	21.8	26.1	30.5	27,250	32,625	38,125	299.8	358.9	419.4
Total[4]	617.9	714.3	810.9	772,375	892,875	1,013,625	8,496.1	9,821.6	11,149.9
Regional total	2,826.6	3,300.9	3,775.5	3,533,250	4,126,125	4,719.375	38,865.8	45,387.4	51,913.1
U.S. total	3,964.5	4,618.6	5,272.7	4,955,625	5,773,250	6,590,875	54,511.9	63,505.8	72,499.6
					Percent				
Regional total as percentage of U.S. total	71.3	71.5	71.6	71.3	71.5	71.6	71.3	71.5	71.6

[1]Data from [*37*]. Projections based on trend extrapolations from 1980 base year.
[2]Based on 1.25 tons of manure and litter per 1,000 birds, dry weight basis [*23, 26, 31, 45*].
[3]Assumes 1 ton of broiler litter/manure, dry weight basis, yields 11 million Btu from direct burning [*26*].
[4]Columns may not total due to rounding.

cessing facilities would be very high. Most use will therefore be concentrated on the farm. This means that capital investment costs for individual farms will be relatively high, particularly for smaller farms. However, for the anaerobic digestion process, there are substantial economies of scale at the low-volume end of digester sizes which could make it feasible for some farms to use this process [*13, 25*]. In addition to size, the cost of an anaerobic digester also varies greatly by type of livestock enterprise and the technical design of the system.

We assumed that economically recoverable manure would be available only from confined livestock and poultry enterprises operating at or above certain minimum-size levels where the anaerobic digestion or direct combustion processes are considered feasible in terms of costs (table 10). Actual costs for individual farms will vary greatly depending upon manure characteristics, digester efficiency, operating practices, and other factors. Efficiency rates for operational digester systems are much lower than maximum output rates under laboratory benchmark conditions due to variations in methanogenic bacteria population, fluctuations in temperature, composition of the manure, and other factors [*14*]. Recoverable energy will also be affected by manure and litter handling losses, storage losses for litter, and conversion losses in the anaerobic digestion and electrical generation processes. These factors were considered in deriving the quantities of economically recoverable energy.

Table 8—Turkeys: Number produced and gross potential volume and energy content of litter and manure

Region and State	Turkeys[1]			Manure volume[2]			Thermal energy content[3]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 birds			*Tons dry weight*			*Billion Btu*		
Southeast:									
Alabama	—	—	—	—	—	—	—	—	—
Florida	—	—	—	—	—	—	—	—	—
Georgia	2,380	2,975	3,570	29,988	37,485	44,982	359.9	449.8	539.8
South Carolina	3,702	4,258	4,813	46,645	53,651	60,644	559.7	643.8	727.7
Total[4]	6,082	7,233	8,383	76,633	91,136	105,626	919.6	1,093.6	1,267.5
Delta States:									
Arkansas	14,500	18,125	21,750	182,700	228,375	274,050	2,192.4	2,740.5	3,288.6
Louisiana	—	—	—	—	—	—	—	—	—
Mississippi	—	—	—	—	—	—	—	—	—
Total[4]	14,500	18,125	21,750	182,700	228,375	274,050	2,192.4	2,740.5	3,288.6
Appalachian:									
Kentucky	—	—	—	—	—	—	—	—	—
North Carolina	23,750	29,688	35,625	299,250	374,069	448,875	3,591.0	4,488.8	5,386.5
Tennessee	—	—	—	—	—	—	—	—	—
Virginia	10,079	12,599	15,120	126,995	158,747	190,512	1,523.9	1,905.0	2,286.1
West Virginia	2,282	2,738	3,195	28,753	34,499	40,257	345.0	414.0	483.1
Total[4]	36,111	45,025	53,940	454,998	567,315	679,644	5,460.0	6,807.8	8,155.7
Regional total	56,693	70,383	84,073	714,332	886,826	1,059,320	8,572.0	10,641.9	12,711.8
U.S. total	164,743	199,339	233,935	2,075,762	2,511,671	2,947,581	24,909.1	30,140.1	35,371.0
					Percent				
Regional total as percentage of U.S. total	34.4	35.3	35.9	34.4	35.3	35.9	34.4	35.3	35.9

— = Data not available.
[1]Data from [*37*]. Projections based on trend extrapolations from 1980 base year.
[2]Based on 12.6 tons of manure and litter per 1,000 birds, dry weight basis, confinement housing [*9, 31, 45*].
[3]Assumes 1 ton of turkey litter/manure, dry weight, yields 12 million Btu from direct burning [*26*].
[4]Columns may not total due to rounding.

Dairy Cows

The economically recoverable volume and potential energy yield of dairy cow manure in the South, given in table 11, are based on manure from dairy farms with herds of 30 cows or more minus 20-percent pasture and handling losses. Estimated manure volume for the region is 1.9 million tons for 1990. With the anaerobic digestion process, the biogas yield would be 3.7 cubic feet per pound of dry weight manure at 35-percent digester efficiency. Biogas production potential for the region is estimated at 14.2 billion cubic feet in 1990.

Biogas is about 60-percent methane gas which has an energy content of approximately 1,000 Btu per cubic foot. Methane from dairy cow manure burned directly as a gas would produce 8.5 trillion Btu of energy in the South in 1990. If the methane gas were used to generate electricity, it would produce 748 gigawatthours in 1990. The energy potential from dairy cows in the South is projected at 14.7 percent of the total U.S. energy potential from dairy cow wastes in 1990.

Hogs and Pigs

Volume and energy values for hogs and pigs in table 12 reflect manure from hog farms with sales of 500 head per year or more minus 10-percent handling losses. With two pig crops per year, the minimum-size farm would have a capacity of 250

Table 9—Nonlaying pullets: Number of birds and gross potential volume and energy content of manure and litter

Region and State	Pullet chickens[1]			Manure volume[2]			Thermal energy content[3]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
	------- *Million birds* -------			--- *1,000 tons dry weight* ---			---------- *Billion Btu* ----------		
Southeast:									
Alabama	12.5	13.2	13.6	37.5	39.6	40.8	412.5	435.6	448.8
Florida	8.7	8.3	7.9	26.1	24.9	23.7	287.1	273.9	260.7
Georgia	17.6	16.4	14.9	52.8	49.2	44.7	580.8	541.2	491.7
South Carolina	4.6	4.7	4.9	13.8	14.1	14.7	151.8	155.1	161.7
Total	43.4	42.6	41.3	130.2	127.8	123.9	1,432.2	1,405.8	1,362.9
Delta States:									
Arkansas	17.3	18.0	19.0	51.9	54.0	57.0	570.9	594.0	627.0
Louisiana	.8	.8	.8	2.4	2.4	2.4	26.4	26.4	26.4
Mississippi	5.6	5.3	4.9	16.8	15.9	14.7	184.8	174.9	161.7
Total	23.7	24.1	24.7	71.1	72.3	74.1	782.1	795.3	815.1
Appalachian:									
Kentucky	.9	.9	.9	2.7	2.7	2.7	29.7	29.7	29.7
North Carolina	9.4	9.9	10.4	28.2	29.7	31.2	310.2	326.7	343.2
Tennessee	2.0	1.6	1.6	6.0	4.8	4.8	66.0	52.8	52.8
Virginia	3.5	3.7	3.7	10.5	11.1	11.1	115.5	122.1	122.1
West Virginia	.2	.2	.2	.6	.6	.6	6.6	6.6	6.6
Total	16.0	16.3	16.8	48.0	48.9	50.4	528.0	537.9	554.4
Regional total	83.1	83.0	82.8	249.3	249.0	248.4	2,742.3	2,739.0	2,732.4
U.S. total	173.1	173.6	173.2	519.3	520.8	519.6	5,712.3	5,728.8	5,715.6
					Percent				
Regional total as percentage of U.S. total	48.0	47.8	47.8	48.0	47.8	47.8	48.0	47.8	47.8

[1]Data from [37]. Pullets on farms Dec. 1 adjusted to reflect total birds raised during the year based on sales-inventory ratios from 1978 Census [39]. Projections based on trend extrapolations from 1980-81 base years.
[2]Based on 3 tons of manure and litter per 1,000 birds, dry weight basis [31].
[3]Assumes 1 ton of pullet manure/litter on a dry weight basis yields 11 million Btu from direct burning [26].

market hogs plus breeding stock. Estimated manure volume for the South is 695,000 tons for 1990. The biogas yield from anaerobic digestion of hog manure would be 5.83 cubic feet per pound of dry weight manure at 55-percent digester efficiency. The biogas production potential for the region is estimated at 8.1 billion cubic feet for 1990.

Biogas is about 60-percent methane gas. If this gas were burned directly, the thermal energy content of the manure for the region would be 4.9 trillion Btu in 1990. Potential energy output of this methane if used to generate electricity would be 427 gigawatthours in 1990. The energy potential from hogs in the South would be 16.7 percent of the total U.S. energy potential from hog wastes in 1990.

Cattle on Feed

Energy values for cattle in table 13 reflect manure from cattle fed on southern farms with sales of 1,000 head or more per year minus 5-percent handling losses. With a turnover ratio of two lots per year, the minimum size farm would be feeding 500 head at one time. Estimated manure volume for the South is 136,700 tons for 1990. The biogas yield from anaerobic digestion would be 5.3 cubic feet per pound of dry weight manure at 50-percent digester efficiency. The biogas production potential for the region is an estimated 1.45 billion cubic feet in 1990.

Biogas is about 60-percent methane gas. Burned directly on the farm, this gas would produce thermal energy amounting to 868 billion Btu in the South in 1990. If used to generate electricity, the potential energy output of the gas for the region would be 76.2 gigawatthours in 1990. The energy potential from cattle on feed in the South accounts for only 1.2 percent of the total U.S. energy potential from fed cattle manure in 1990.

Laying Hens

Energy values for laying hens in table 14 reflect manure from poultry farms with flocks of 20,000 hens or more minus 3-percent handling losses. Estimated manure volume for the South is 896,000 tons for 1990. The biogas yield from anaerobic digestion would be 6.3 cubic feet per pound of dry weight manure at 65-percent digester efficiency. The biogas production potential for the region is 11.1 billion cubic feet for 1990.

Biogas is about 60-percent methane gas. If this gas were burned directly, the thermal energy content of the manure for the region would be 6.7 trillion Btu in 1990. If the methane gas were used to generate electricity, it would produce 585 gigawatthours in the South in 1990. The energy potential from laying hens in the South is projected to be 35.8 percent of the total U.S. energy potential from laying hen wastes in 1990.

Broilers

The energy values for broilers in table 15 reflect manure from broiler farms with sales of 60,000 birds per year or more minus 3-percent handling losses. With production of five lots per year, the minimum-size farm would have a capacity of 12,000 birds. Estimated manure volume for the South is 4.3 million tons for 1990.

Broiler litter and manure will yield about 11 million Btu per ton dry weight in the direct combustion process, producing 47.7 trillion Btu of thermal energy in the South in 1990. This potential energy from

Table 10—Minimum-size enterprises and capital investment costs for economically recoverable energy systems for livestock and poultry manure in the South, 1980

Species	Minimum-size unit[1]	Energy conversion system[2]	Capital investment costs[3]	Source
	Number		*Dollars*	*Reference*
Dairy cows	30	AD	25,000	[*4, 14, 16*]
Swine	250	AD	51,000	[*10, 11, 14*]
Fed beef	500	AD	65,000	[*13, 14*]
Laying hens	20,000	AD	50,000	[*14, 17, 28*]
Broilers	12,000	DC	18,000	[*24, 30*]
Turkeys	15,000	DC	18,000	[*24*]
Pullets	15,000	DC	18,000	[*24*]

[1]Refers to animals or birds on farm at any one time. However, there are typically two pig crops per year produced, two lots of fed beef, at least five lots of broilers, and two flocks of turkeys and pullets.

[2]Conversion system AD is anaerobic digestion and DC is direct combustion.

[3]Based primarily on studies conducted in late seventies through 1981. Reflects lowest costs for minimum-size units. Does not include engine generator costs of at least $8,000 for electricity production in the AD process. Litter storage and conveying system at a cost of $6,000 included in the DC process.

Table 11—Dairy cows: Animal numbers and economically recoverable volume and potential energy yield from manure with anaerobic digestion

Region and State	Dairy cows[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	----- *1,000 head* -----			-- *1,000 tons dry weight* --			--- *Billion cubic feet* ---			------- *Billion Btu* -------			--------- *gWh* ---------		
Southeast:															
Alabama	57	53	51	89	83	80	0.6	0.6	0.6	360	360	360	31.6	31.6	31.6
Florida	182	180	179	284	281	279	2.1	2.1	2.1	1,260	1,260	1,260	110.7	110.7	110.7
Georgia	122	122	122	190	190	190	1.4	1.4	1.4	840	840	840	73.8	73.8	73.8
South Carolina	45	42	40	70	66	62	.5	.5	.5	300	300	300	26.4	26.4	26.4
Total	406	397	392	633	620	611	4.6	4.6	4.6	2,760	2,760	2,760	242.5	242.5	242.5
Delta States:															
Arkansas	65	63	61	101	98	95	.7	.7	.7	420	420	420	36.9	36.9	36.9
Louisiana	105	99	95	164	154	148	1.2	1.1	1.1	720	660	660	63.2	58.0	58.0
Mississippi	84	80	75	131	125	117	1.0	.9	.9	600	540	540	52.7	47.4	47.4
Total	254	242	231	396	377	360	2.9	2.7	2.7	1,740	1,620	1,620	152.8	142.3	142.3
Appalachian:															
Kentucky	169	161	152	264	251	237	2.0	1.9	1.8	1,200	1,140	1,080	105.4	100.1	94.9
North Carolina	118	113	107	184	176	167	1.4	1.3	1.2	840	780	720	73.8	68.5	63.2
Tennessee	168	168	168	262	262	262	1.9	1.9	1.9	1,140	1,140	1,140	100.1	100.1	100.1
Virginia	148	148	148	231	231	231	1.7	1.7	1.7	1,020	1,020	1,020	89.6	89.6	89.6
West Virginia	27	27	27	42	42	42	.3	.3	.3	180	180	180	15.8	15.8	15.8
Total	630	617	602	983	962	939	7.3	7.1	6.9	4,380	4,260	4,140	384.7	374.1	363.6
Regional total	1,290	1,256	1,225	2,012	1,959	1,910	14.8	14.4	14.2	8,880	8,640	8,520	780.0	758.9	748.4
U.S. total	9,128	8,763	8,398	14,240	13,670	13,101	105.4	101.2	96.9	63,240	60,720	58,140	5,555.0	5,333.6	5,107.0
Regional total as percentage of U.S. total								*Percent*							
	14.1	14.3	14.6	14.1	14.3	14.6	14.0	14.2	14.7	14.0	14.2	14.7	14.0	14.2	14.7

[1]Data from table 3 adjusted to include only dairy cows on farms with herds of 30 cows or more based on size categories from 1978 Census [*39*].
[2]Based on 1.95 tons manure per dairy cow, dry weight basis, minus 20-percent pasture and handling losses [*45*].
[3]Based on 3.7 cubic feet of biogas per pound of manure, dry weight basis, at 35-percent digester efficiency [*4,14*].
[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].
[5]Based on 3.4153 billion Btu per gWh and 30-percent electrical conversion efficiency [*16, 22*].

Table 12—Swine: Animal numbers and economically recoverable volume and potential energy yield from manure with anaerobic digestion

Region and State	Hogs and pigs[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 head			*1,000 tons dry weight*			*Million cubic feet*			*Billion Btu*			*gWh*		
Southeast:															
Alabama	637	653	669	40	41	42	466	478	490	279.6	286.8	294.0	24.6	25.2	25.8
Florida	267	280	293	17	18	18	198	210	210	118.8	126.0	126.0	10.4	11.1	11.1
Georgia	1,763	1,815	1,918	111	114	121	1,294	1,329	1,411	776.4	797.4	846.6	68.2	70.0	74.4
South Carolina	538	563	583	34	35	37	396	408	431	237.6	244.8	258.6	20.9	21.5	22.7
Total	3,205	3,311	3,463	202	208	218	2,354	2,425	2,542	1,412.4	1,455.0	1,525.2	124.1	127.8	134.0
Delta States:															
Arkansas	781	897	1,014	49	57	64	571	665	746	342.6	399.0	447.6	30.1	35.0	39.3
Louisiana	64	60	57	4	4	4	47	47	47	28.2	28.2	28.2	2.5	2.5	2.5
Mississippi	286	293	300	18	18	19	210	210	222	126.0	126.0	133.2	11.1	11.1	11.7
Total	1,131	1,250	1,371	71	79	87	828	922	1,015	496.8	553.2	609.0	43.7	48.6	53.5
Appalachian:															
Kentucky	936	959	982	59	60	62	688	700	723	412.8	420.0	433.8	36.3	36.9	38.1
North Carolina	3,055	3,293	3,531	192	207	222	2,239	2,414	2,589	1,343.4	1,448.4	1,553.4	118.0	127.2	136.5
Tennessee	692	726	761	44	46	48	513	536	560	307.8	321.6	336.0	27.0	28.2	29.5
Virginia	742	816	890	47	51	56	548	595	653	328.8	357.0	391.8	28.9	31.4	34.4
West Virginia	25	25	26	2	2	2	23	23	23	13.8	13.8	13.8	1.2	1.2	1.2
Total	5,450	5,819	6,190	344	366	390	4,011	4,268	4,548	2,406.6	2,560.8	2,728.8	211.4	224.9	239.7
Regional total	9,786	10,380	11,024	617	653	695	7,193	7,615	8,105	4,315.8	4,569.0	4,863.0	379.2	401.3	427.2
U.S. total	62,091	64,127	66,162	3,912	4,040	4,168	45,614	47,106	48,599	27,386.4	28,263.6	29,159.4	2,405.6	2,482.7	2,561.4
Regional total as percentage of U.S. total							*Percent*								
	15.8	16.2	16.7	15.8	16.2	16.7	15.8	16.2	16.7	15.8	16.2	16.7	15.8	16.2	16.7

[1]Data from table 4 adjusted to include only animals from farms with sales of 500 head per year or more based on size categories from 1978 Census [*39*].
[2]Based on 0.07 ton of manure per animal, dry weight basis, minus 10-percent handling losses [*10, 45*].
[3]Based on 5.83 cubic feet of biogas per pound of manure, dry weight basis, at 55-percent digester efficiency [*14*].
[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].
[5]Based on 3.4153 billion Btu per gWh and 30-percent electrical conversion efficiency [*16, 22*].

Table 13—Cattle on feed: Animal numbers and economically recoverable volume and potential energy content of manure with anaerobic digestion

Region and State	Fed beef[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 head			*1,000 tons dry weight*			*Million cubic feet*			*Billion Btu*			*gWh*		
Southeast:															
Alabama	31.3	38.2	38.2	18.4	22.5	22.5	195	239	239	117	143	143	10.3	12.6	12.6
Florida	91.2	89.7	91.2	53.7	52.8	53.7	569	560	569	341	336	341	30.0	29.5	30.0
Georgia	32.3	32.3	32.3	19.0	19.0	19.0	201	201	201	121	121	121	10.6	10.6	10.6
South Carolina	10.5	10.5	10.5	6.2	6.2	6.2	66	66	66	40	40	40	3.5	3.5	3.5
Total	165.3	170.7	172.2	97.3	100.5	101.4	1,031	1,066	1,075	619	640	645	54.4	56.2	36.7
Delta States:															
Arkansas	7.5	11.4	11.4	4.4	6.7	6.7	47	71	71	28	43	43	2.5	3.8	3.8
Louisiana	1.4	1.4	1.4	.8	.8	.8	8	8	8	5	5	5	.4	.4	.4
Mississippi	14.4	9.6	14.4	8.5	5.7	8.5	90	60	90	54	36	54	4.7	3.2	4.7
Total	23.3	22.4	27.2	13.7	13.2	16.0	145	139	169	87	84	102	7.6	7.4	8.9
Appalachian:															
Kentucky	4.4	5.8	5.8	2.6	3.4	3.4	28	34	34	17	20	20	1.5	1.8	1.8
North Carolina	5.1	5.1	5.1	3.0	3.0	3.0	32	32	32	19	19	19	1.7	1.7	1.7
Tennessee	11.1	14.6	14.6	6.5	8.6	8.6	69	91	91	41	55	55	3.6	4.8	4.8
Virginia	6.0	5.4	6.0	3.5	3.2	3.5	37	34	37	22	20	22	1.9	1.8	1.9
West Virginia	1.4	1.1	1.4	.8	.6	.8	8	6	8	5	4	5	.4	.4	.4
Total	28.0	32.0	32.9	16.4	18.8	19.3	174	197	202	104	118	121	9.1	10.5	10.6
Regional total	216.6	225.1	232.3	127.4	132.5	136.7	1,350	1,402	1,446	810	842	868	71.1	74.1	76.2
U.S. total	17,479.2	18,571.2	19,633.8	10,295.2	10,938.4	11,564.3	109,129	115,947	122,582	65,477	69,568	73,549	5,751.5	6,110.9	6,460.5
Regional total as percentage of U.S. total	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

Percent

[1]Data from table 5 adjusted to include only cattle fed on farms with sales of 1,000 head or more per year based on size categories from 1978 Census [*39*].
[2]Based on 0.62 ton of manure per animal, dry weight basis, minus 5-percent handling losses [*13, 22, 45*].
[3]Based on 5.3 cubic feet of biogas per pound of manure, dry weight basis, at 50-percent digester efficiency [*14*].
[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].
[5]Based on 3.4153 billion Btu per gWh and 30-percent electrical conversion efficiency.

Table 14—Laying hens: Number of birds and economically recoverable volume and potential energy content of manure with anaerobic digestion

Region and State	Laying hens[1]			Manure volume[2]			Biogas production potential[3]			Thermal energy content[4]			Electrical energy potential[5]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
	----- *Million birds* -----			-- *1,000 tons dry weight* --			--- *Billion cubic feet* ---			------- *Billion Btu* -------			----------*gWh*----------		
Southeast:															
Alabama	8.5	9.0	9.4	104	110	115	1.3	1.4	1.4	780	840	840	68.5	73.8	73.8
Florida	11.4	11.9	12.5	139	145	153	1.8	1.8	1.9	1,080	1,080	1,140	94.9	94.9	100.1
Georgia	15.8	15.2	14.6	193	186	178	2.4	2.3	2.2	1,440	1,380	1,320	126.5	121.2	115.9
South Carolina	5.2	5.4	5.7	64	66	70	.8	.8	.9	480	480	540	42.2	42.2	47.4
Total	40.9	41.5	42.2	500	507	516	6.3	6.3	6.4	3,780	3,780	3,840	332.1	332.1	337.2
Delta States:															
Arkansas	10.8	11.3	11.8	132	138	144	1.7	1.7	1.8	1,020	1,020	1,080	89.6	89.6	94.9
Louisiana	1.1	1.1	1.0	13	13	12	.2	.2	.2	120	120	120	10.5	10.5	10.5
Mississippi	4.0	3.7	3.2	49	45	39	.6	.6	.5	360	360	300	31.6	31.6	26.4
Total	15.9	16.1	16.0	194	196	195	2.5	2.5	2.5	1,500	1,500	1,500	131.7	131.7	131.8
Appalachian:															
Kentucky	1.4	1.4	1.4	17	17	17	.2	.2	.2	120	120	120	10.5	10.5	10.5
North Carolina	7.4	7.8	8.1	90	95	99	1.1	1.2	1.2	660	720	720	58.0	63.2	63.2
Tennessee	3.0	2.9	2.9	37	35	35	.5	.4	.4	300	240	240	26.4	21.1	21.1
Virginia	2.6	2.7	2.7	32	33	33	.4	.4	.4	240	240	240	21.1	21.1	21.1
West Virginia	.1	.1	.1	1	1	1	.01	.01	.01	6	6	6	.5	.5	.5
Total	14.5	14.9	15.2	177	181	185	2.2	2.2	2.2	1,326	1,326	1,326	116.5	116.4	116.4
Regional total	71.3	72.5	73.4	871	884	896	11.0	11.0	11.1	6,606	6,606	6,666	580.3	580.2	585.4
U.S. total	207.2	204.1	201.0	2,532	2,495	2,457	31.9	31.4	31.0	19,140	18,840	18,600	1,681.3	1,654.9	1,633.8
Regional total as percentage of U.S. total								*Percent*							
	34.4	35.5	36.5	34.4	35.4	36.5	34.5	35.0	35.8	34.5	35.1	35.8	34.5	35.1	35.8

[1]Data from table 6 adjusted to include only birds on farms with flocks of 20,000 hens or more based on size categories from 1978 Census [*39*].
[2]Based on 12.6 tons of manure per 1,000 birds, dry weight basis, minus 3-percent handling losses [*9, 20, 31, 45*].
[3]Based on 6.3 cubic feet of biogas per pound of manure, dry weight basis, at 65-percent digester efficiency [*14*].
[4]Based on 600 Btu per cubic foot of biogas at 60-percent methane content. Methane gas yields 1,000 Btu per cubic foot [*29*].
[5]Based on 3.4153 billion Btu per gWh and 30-percent electrical conversion efficiency [*16, 22*].

broilers in the South would account for almost 72 percent of the total U.S. energy potential from broiler wastes in 1990.

Turkeys

Energy values for turkeys in table 16 reflect manure from turkey farms with sales of 30,000 birds per year or more minus 20-percent range and handling losses. With production of two flocks per year, the minimum-size farm would have a capacity of 15,000 turkeys. Estimated manure volume for the South is more than 750,000 tons for 1990.

Turkey litter and manure burned directly will yield about 12 million Btu per ton dry weight. Burning the manure for heating would provide a thermal energy content of 9 trillion Btu for the region in 1990, representing 36.6 percent of the total U.S. energy potential from turkey wastes in that year.

Pullets

Energy values for pullets in table 17 reflect manure from pullet-growing farms with sales of 30,000 birds or more per year minus 3-percent handling losses. With production of two flocks per year, the minimum-size farm would have a capacity of 15,000 pullets. Estimated manure volume for the South is 175,764 tons for 1990.

Table 15—Broilers: Number produced and economically recoverable volume and potential energy content of litter and manure

Region and State	Broilers[1]			Manure volume[2]			Thermal energy content[3]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
	Million birds			*Tons dry weight*			*Billion Btu*		
Southeast:									
Alabama	465.0	539.5	613.8	563,813	654,144	744,233	6,201.9	7,195.6	8,186.6
Florida	85.4	103.8	122.1	103,548	125,858	148,046	1,139.0	1,384.4	1,628.5
Georgia	539.5	609.6	679.7	654,144	739,140	824,136	7,195.6	8,130.5	9,065.6
South Carolina	40.5	46.6	52.7	49,106	56,503	63,899	540.2	621.5	702.9
Total	1,130.4	1,299.5	1,468.3	1,370,611	1,575,645	1,780,314	15,076.7	17,332.0	19,583.5
Delta States:									
Arkansas	603.2	726.8	850.4	731,380	881,245	1,031,110	8,045.2	9,693.7	11,342.2
Louisiana	98.0	121.0	144.0	118,825	146,713	174,600	1,307.1	1,613.8	1,920.6
Mississippi	267.7	311.9	356.1	324,586	378,179	431,771	3,570.4	4,160.0	4,749.5
Total	968.9	1,159.7	1,350.5	1,174,791	1,406,137	1,637,481	12,922.7	15,467.5	18,012.3
Appalachian:									
Kentucky	2.3	2.3	2.3	2,789	2,789	2,789	30.7	30.7	30.7
North Carolina	371.6	425.5	479.4	450,565	515,919	581,273	4,956.2	5,675.1	6,394.0
Tennessee	59.5	66.4	73.2	72,144	80,510	88,755	793.6	885.6	976.3
Virginia	121.3	146.8	172.2	147,076	177,995	208,793	1,617.8	1,957.9	2,296.7
West Virginia	20.3	24.3	28.4	24,614	29,464	34,435	270.8	324.1	378.8
Total	575.0	665.3	755.5	697,188	806,677	916,045	7,669.1	8,873.4	10,076.5
Regional total	2,674.3	3,124.5	3,574.3	3,242,590	3,788,459	4,333,840	35,668.5	41,672.9	47,672.3
U.S. total	3,750.4	4,369.2	4,988.0	4,547,360	5,297,655	6,047,950	50,021.0	58,274.2	66,527.5
					Percent				
Regional total as percentage of U.S. total	71.3	71.5	71.7	71.3	71.5	71.7	71.3	71.5	71.7

[1]Data from table 7 adjusted to include only birds from farms with sales of 60,000 birds per year or more based on size categories from 1978 Census [*39*].
[2]Based on 1.25 tons of manure and litter per 1,000 birds, dry weight basis, minus 3-percent handling losses [*26, 31*].
[3]Assumes 1 ton of broiler litter/manure, dry weight basis, yields 11 million Btu from direct burning [*26*].

With the direct combustion process, pullet litter and manure will yield about 11 million Btu per ton dry weight. Burned directly, the litter and manure would provide 1.93 trillion Btu in the South in 1990, representing 43.1 percent of the total U.S. energy potential from pullet wastes in 1990.

Total Quantity and Potential Value of Recoverable Energy from Livestock and Poultry Wastes

Potential recoverable energy from livestock and poultry wastes in the South consists of two primary types: (1) methane gas from anaerobic digestion, and (2) thermal energy from direct combustion of manure and litter. Methane gas can be burned directly or converted into electricity by engine generators. The value of this energy will therefore depend on its form: that is, whether used for methane gas, electricity, or for direct combustion; its location; and the type of conventional fuel which it displaces.

Methane Gas Production

The economically recoverable methane gas production potential from anaerobic digestion in the South was 20.6 billion cubic feet in 1980 with 43 percent of this energy from dairy cow enterprises, 32 percent from laying hens, 21 percent from hogs, and 4 percent from fed beef (table 18). This production was 11.7 percent of the total potential output of meth-

Table 16—Turkeys: Number produced and economically recoverable volume and potential energy content of litter and manure

Region and State	Turkeys[1]			Manure volume[2]			Thermal energy content[3]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
	1,000 birds			*Tons dry weight*			*Billion Btu*		
Southeast:									
Alabama	—	—	—	—	—	—	—	—	—
Florida	—	—	—	—	—	—	—	—	—
Georgia	1,833	2,291	2,749	18,477	23,093	27,710	221.7	277.1	332.5
South Carolina	3,147	3,619	4,091	31,722	36,480	41,237	380.7	437.8	494.8
Total	4,980	5,910	6,840	50,199	59,573	68,947	602.4	714.9	827.3
Delta States:									
Arkansas	12,905	16,131	19,358	130,082	162,600	195,129	1,561.0	1,951.2	2,341.5
Louisiana	—	—	—	—	—	—	—	—	—
Mississippi	—	—	—	—	—	—	—	—	—
Total	12,905	16,131	19,358	130,082	162,600	195,129	1,561.0	1,951.2	2,341.5
Appalachian:									
Kentucky	—	—	—	—	—	—	—	—	—
North Carolina	22,308	27,886	33,463	224,865	281,091	337,307	2,698.4	3,373.1	4,047.7
Tennessee	—	—	—	—	—	—	—	—	—
Virginia	7,962	9,953	11,945	80,257	100,326	120,406	963.1	1,203.9	1,444.9
West Virginia	2,008	2,409	2,812	20,241	24,283	28,345	242.9	291.4	340.1
Total	32,278	40,248	48,220	325,363	405,700	486,058	3,904.4	4,868.4	5,832.7
Regional total	50,163	62,289	74,418	505,644	627,873	750,134	6,067.8	7,534.5	9,001.5
U.S. total	143,326	173,425	203,523	1,444,726	1,748,124	2,048,790	17,336.7	20,977.5	24,585.5
				Percent					
Regional total as percentage of U.S. total	35.0	35.9	36.6	35.0	35.9	36.6	35.0	35.9	36.6

— = Data not available.

[1]Data from table 8 adjusted to include only turkeys from farms with sales of 30,000 birds per year or more based on size categories from 1978 Census [*39*].

[2]Based on 12.6 tons of manure and litter per 1,000 birds, dry weight basis, minus 20-percent range and handling losses [*9, 31, 45*].

[3]Assumes 1 ton of turkey litter/manure, dry weight basis, yields 12 million Btu from direct burning [*26*].

ane gas from these types of enterprises in the United States in 1980. The major potential producing States in the region were Georgia, North Carolina, and Florida, which accounted for 43 percent of the region's methane gas potential. However, due to the diversity of these enterprises, production potential was generally widespread throughout the region except for West Virginia and Louisiana, which had a relatively small number of livestock and poultry farms. Projected 1985 and 1990 levels of methane gas production show little change from 1980 levels for the South.

The potential value of this methane gas depends on whether it is used to replace natural gas, LP gas, or electricity. Natural gas is only available in certain areas of the South, but it is a good substitute for methane gas where available. However, LP gas is the most common type of fuel used on farms or in rural areas in the South. Methane gas used as a substitute for natural gas in the region in 1980 would have been valued at $76.7 million, compared with $146.6 million if it had been used as a substitute for LP gas (table 19). This higher value for LP gas is expected since natural gas has traditionally been priced much lower than LP gas on a Btu basis. For 1985 and 1990, however, the price of natural gas is expected to increase much faster than LP gas due to deregulation of the natural gas industry now underway. The value of the potential methane gas

Table 17—Nonlaying pullets: Number of birds and economically recoverable volume and potential energy content of manure and litter

Region and State	Pullet chickens[1]			Manure volume[2]			Thermal energy content[3]		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
	Million birds			*Tons dry weight*			*Billion Btu*		
Southeast:									
Alabama	7.4	7.8	8.0	21,534	22,698	23,280	236.9	249.7	256.1
Florida	7.8	7.5	7.1	22,698	21,825	20,661	249.7	240.1	227.3
Georgia	11.6	10.8	9.8	33,756	31,428	28,518	371.3	345.7	313.7
South Carolina	4.1	4.2	4.4	11,931	12,222	12,804	131.2	134.4	140.8
Total	30.9	30.3	29.3	89,919	88,173	85,263	989.1	969.9	937.9
Delta States:									
Arkansas	12.1	12.6	13.3	35,211	36,666	38,703	387.3	403.3	425.7
Louisiana	.7	.7	.7	2,037	2,037	2,037	22.4	22.4	22.4
Mississippi	4.8	4.5	4.2	13,968	13,095	12,222	153.6	144.0	134.4
Total	17.6	17.8	18.2	51,216	51,798	52,962	563.3	569.7	682.5
Appalachian:									
Kentucky	.6	.6	.6	1,746	1,746	1,746	19.2	19.2	19.2
North Carolina	7.3	7.7	8.1	21,243	22,407	23,571	233.7	246.5	259.3
Tennessee	1.6	1.3	1.3	4,656	3,783	3,783	51.2	41.6	41.6
Virginia	2.7	2.8	2.8	7,857	8,148	8,148	86.4	89.6	89.6
West Virginia	.1	.1	.1	291	291	291	3.2	3.2	3.2
Total	12.3	12.5	12.9	35,793	36,375	37,539	393.7	400.1	412.9
Regional total	60.8	60.6	60.4	176,928	176,346	175,764	1,946.1	1,939.8	1,933.4
U.S. total	140.2	140.6	140.3	407,982	409,146	408,273	4,487.8	4,500.6	4,491.0
					Percent				
Regional total as percentage of U.S. total	43.4	43.1	43.1	43.4	43.1	43.1	43.4	43.1	43.1

[1]Data from table 9 adjusted to include only birds from farms with sales of 30,000 birds or more per year based on size categories from 1978 Census [*39*].
[2]Based on 3 tons of manure and litter per 1,000 birds, dry weight basis, minus 3-percent handling losses [*31*].
[3]Assumes 1 ton of pullet litter/manure, dry weight basis, yields 11 million Btu from direct burning [*26*].

Table 18—Methane gas: Quantity economically recoverable from anaerobic digestion of animal and poultry manure[1]

Region and State	Dairy cows			Fed beef			Hogs and pigs			Laying hens			Total		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
							Million cubic feet								
Southeast:															
Alabama	360	360	360	117	143	143	280	287	294	780	840	840	1,537	1,630	1,637
Florida	1,260	1,260	1,260	341	336	341	119	126	126	1,080	1,080	1,140	2,800	2,802	2,867
Georgia	840	840	840	121	121	121	776	797	847	1,440	1,380	1,320	3,177	3,138	3,128
South Carolina	300	300	300	40	40	40	238	245	259	480	480	540	1,058	1,065	1,139
Total	2,760	2,760	2,760	619	640	645	1,413	1,455	1,526	3,780	3,780	3,840	8,572	8,635	8,771
Delta States:															
Arkansas	420	420	420	28	43	43	343	399	448	1,020	1,020	1,080	1,811	1,882	1,991
Louisiana	720	660	660	5	5	5	28	28	28	120	120	120	873	813	813
Mississippi	600	540	540	54	36	54	126	126	133	360	360	300	1,140	1,062	1,027
Total	1,740	1,620	1,620	87	84	102	497	553	609	1,500	1,500	1,500	3,824	3,757	3,831
Appalachian:															
Kentucky	1,200	1,140	1,080	17	20	20	413	420	434	120	120	120	1,750	1,700	1,654
North Carolina	840	780	720	19	19	19	1,343	1,448	1,553	660	720	720	2,862	2,967	3,012
Tennessee	1,140	1,140	1,140	41	55	55	308	322	336	300	240	240	1,789	1,757	1,771
Virginia	1,020	1,020	1,020	22	20	22	329	357	392	240	240	240	1,611	1,537	1,674
West Virginia	180	180	180	5	4	5	14	14	14	6	6	6	205	204	205
Total	4,380	4,260	4,140	104	118	121	2,407	2,561	2,729	1,326	1,326	1,326	8,217	8,165	8,316
Regional total	8,880	8,640	8,520	810	842	868	4,317	4,569	4,864	6,606	6,606	6,666	20,613	20,557	20,918
U.S. total	63,240	60,720	58,140	65,477	69,568	73,549	27,368	28,264	29,159	19,140	18,840	18,600	175,225	177,392	179,448
							Percent								
Regional total as percentage of U.S. total	14.0	14.2	14.7	1.2	1.2	1.2	15.8	16.2	16.7	34.5	35.0	35.8	11.7	11.6	11.7

[1]Based on data from tables 11 to 14 with a biogas yield of 60-percent methane gas [*10, 14, 25*].

Table 19—Methane: Potential value of gas as a substitute for natural or LP gas[1]

Region and State	Natural gas						LP gas					
	1980		1985		1990		1980		1985		1990	
	Price[2]	Value	Price[2]	Value	Price[2]	Value	Price[3]	Value	Price[3]	Value	Price[3]	Value
	$/MMBtu	*$ million*	*$/MMBtu*	*$ million*	*$/MMBtu*	*$ million*	*Cents/gal*	*$ million*	*Cents/gal*	*$ million*	*Cents/gal*	*$ million*
Southeast:												
Alabama	4.11	6.3	8.47	13.8	10.77	17.6	62.67	10.1	96.20	16.5	122.52	21.1
Florida	4.53	12.7	9.33	26.1	11.87	34.0	78.83	23.2	121.00	35.7	154.11	46.5
Georgia	4.06	12.9	8.36	26.2	10.64	33.3	66.75	22.3	102.46	33.8	130.50	43.0
South Carolina	4.12	4.4	8.48	9.0	10.79	12.3	68.33	7.6	104.89	11.8	133.59	16.0
Total	4.23	36.3	8.71	75.1	11.08	97.2	70.16	63.2	107.70	97.8	137.16	126.6
Delta States:												
Arkansas	2.31	4.2	4.76	9.0	6.05	12.0	63.67	12.1	97.73	19.4	124.47	26.1
Louisiana	3.06	2.7	6.30	5.1	8.02	6.5	70.42	6.5	108.09	9.3	137.67	11.8
Mississippi	3.38	3.9	6.96	7.4	8.86	9.1	67.42	8.1	103.49	11.6	131.81	14.2
Total	2.80	10.8	5.79	21.5	7.34	27.6	66.33	26.7	101.82	40.3	129.68	52.1
Appalachian:												
Kentucky	3.08	5.4	6.34	10.8	8.07	13.3	63.50	11.7	97.47	17.4	124.14	21.6
North Carolina	4.00	11.4	8.24	24.4	10.48	31.6	63.42	19.1	97.35	30.4	123.99	39.3
Tennessee	2.94	5.3	6.06	10.6	7.70	13.6	70.00	13.2	107.45	19.9	136.85	25.5
Virginia	4.24	6.8	8.73	13.4	11.11	18.6	66.58	11.3	102.20	16.5	130.16	22.9
West Virginia	3.61	.7	7.42	1.5	9.43	1.9	66.58	1.4	102.20	2.2	130.16	2.8
Total	3.61	29.6	7.42	60.7	9.43	79.0	63.91	56.7	98.10	86.4	124.94	112.1
Regional total	3.72	76.7	7.66	157.3	9.75	203.8	66.96	146.6	102.78	224.5	130.91	290.8
U.S. total	3.61	632.6	7.42	1,316.2	9.43	1,692.2	61.90	1,141.7	95.02	1,774.3	121.01	2,285.8
						Percent						
Regional total as percentage of U.S. total	—	12.1	—	12.7	—	12.0	—	12.8	—	12.7	—	12.7

— = Not applicable.

[1]Based on volume data from table 18, with 95 cubic feet of methane gas (or natural gas) equivalent in Btu content to 1 gallon of LP gas. One gallon of LP gas yields 95,000 Btu, and 1 cubic foot of natural gas or methane gas yields 1,000 Btu. Includes energy from economically recoverable manure from dairy cows, hogs, feedlot beef, and laying hens.

[2]Based on average residential gas rates by State for 1980 [*1*] and projected U.S. prices for 1985 and 1990 [*2*]. Prices for individual States assumed to increase from 1980 at same percentage rate as projected U.S. average prices. Regional prices are weighted averages.

[3]Based on prices paid by farmers by State for 1980 [*36*] and projected U.S. prices for 1985 and 1990. Prices for individual States assumed to increase from 1980 at same percentage rate as projected U.S. average prices. Regional prices are weighted averages.

produced in the region in 1990 would therefore be $203.8 million if substituted for natural gas and $290.8 million if substituted for LP gas (table 19). The divergence between the value of these two types of conventional fuels is thus expected to narrow by 1990.

Electricity Production

The electricity production potential from methane gas from anaerobic digestion for the region would be 1,810 gigawatthours in 1980 with 43 percent of this energy derived from dairy cow enterprises, 32 percent from laying hens, 21 percent from hogs, and 4 percent from fed beef (table 20). This production potential was 11.8 percent of the total potential output of electricity from these types of enterprises in the United States in 1980. Major producing States in the region were Georgia, North Carolina, and Florida, which accounted for 43 percent of the electricity potential in the region. However, production could occur throughout the region except for West Virginia, which had a relatively small number of livestock and poultry farms. The projected levels of electricity production for the South for 1985 and 1990 show only very slight increases from 1980 levels.

The potential value of this electricity depends on the electrical power rates in the various States. In 1980, these prices varied from a low of 3.5 cents per kilowatthour in Tennessee to 5.9 cents in Florida. For the region as a whole, electric power rates were 4.7 cents per kilowatthour, resulting in a value of $85.3 million for the electricity potential from methane gas in 1980 (table 21). States with the highest potential values were Florida, Georgia, and North Carolina. With higher price levels projected for electricity in the eighties, the potential value of electricity from methane gas production in the South will increase substantially to $173 million in 1990 (table 21). However, the values for electricity in 1985 and 1990 will still be substantially lower than using the methane gas as a direct substitute for natural or LP gas. In 1990, for example, the highest value use for methane gas would be $290.8 million when used as a replacement for LP gas, $203.8 million when replacing natural gas, and $173 million when used to generate electricity.

Direct Burning of Litter

The economically recoverable thermal energy potential from burning litter and manure from broiler, turkey, and pullet enterprises in the South was 43.7 trillion Btu in 1980, with 82 percent of this energy derived from broiler farms, 14 percent from turkey farms, and 4 percent from pullet growers (table 22). This production was 60.8 percent of the total potential thermal energy output from these types of enterprises in the United States in 1980.

Major producing States in the region were Arkansas, North Carolina, Georgia, and Alabama, which accounted for 74 percent of the energy from direct burning of manure and litter in the region. However, energy from direct burning was generally available throughout the region except for Kentucky, Tennessee, and West Virginia, which had a relatively small number of poultry farms. Projected levels of thermal energy potential from direct burning of poultry manure in the South show significant increases in the eighties, rising to 58.6 trillion Btu in 1990 (table 22).

The potential value of energy from poultry litter and manure depends on whether it is used to replace wood shavings or chips for direct burning or as a substitute for LP gas. LP gas is the most common fuel used on southern poultry farms, but wood fuels are being used on some farms. Energy from burning wood residues would have a much lower value than conventional fuels such as LP gas. If the poultry litter were used as a substitute for wood shavings, the value of the thermal energy produced in the region in 1980 would be $63.8 million, compared with $301.1 million if used to replace LP gas (table 23). Values for other conventional fuels such as natural gas would fall between these levels. In 1985 and 1990, however, these values are expected to increase substantially due to higher prices for all types of fuels. The potential value of poultry litter used to replace softwood shavings in the South would be $171.2 million in 1990 given the price projections used in this study; the value for litter used as a substitute for LP gas would be $789.5 million in 1990 (table 23).

Table 20—Electricity: Quantity of economically recoverable energy from anaerobic digestion of animal and poultry manure[1]

Region and State	Dairy			Fed beef			Hogs and pigs			Laying hens			Total		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
							Gigawatthours								
Southeast:															
Alabama	31.6	31.6	31.6	10.3	12.6	12.6	24.6	25.2	25.8	68.5	73.8	73.8	135.0	143.2	143.8
Florida	110.7	110.7	110.7	30.0	29.5	30.0	10.4	11.1	11.1	94.9	94.9	100.1	246.0	246.2	251.9
Georgia	73.8	73.8	73.8	10.6	10.6	10.6	68.2	70.0	74.4	126.5	121.2	115.9	279.1	275.6	274.7
South Carolina	26.4	26.4	26.4	3.5	3.5	3.5	20.9	21.5	22.7	42.2	42.2	47.4	93.0	93.6	100.0
Total	242.5	242.5	242.5	54.4	56.2	56.7	124.1	127.8	134.0	332.1	332.1	337.2	753.1	758.6	770.4
Delta States:															
Arkansas	36.9	36.9	36.9	2.5	3.8	3.8	30.1	35.0	39.3	89.5	89.6	94.9	159.1	165.3	174.9
Louisiana	63.2	58.0	58.0	.4	.4	.4	2.5	2.5	2.5	10.5	10.5	10.5	76.6	71.4	71.4
Mississippi	52.7	47.4	47.4	4.7	3.2	4.7	11.1	11.0	11.7	31.6	31.6	26.4	100.1	93.2	90.2
Total	152.8	142.3	124.3	7.6	7.4	8.9	43.7	48.5	53.5	131.7	131.8	131.8	335.8	329.9	336.5
Appalachian:															
Kentucky	105.4	100.1	94.9	1.5	1.8	1.8	36.3	36.9	38.1	10.5	10.5	10.5	153.7	149.3	145.3
North Carolina	73.8	68.5	63.2	1.7	1.7	1.7	118.0	127.2	136.5	58.0	63.2	63.2	251.5	260.6	264.6
Tennessee	100.1	100.1	100.1	3.6	4.8	4.8	27.0	28.2	29.5	26.4	21.0	21.0	157.1	154.1	155.4
Virginia	89.6	89.6	89.6	1.9	1.8	1.9	28.9	31.4	34.4	21.1	21.0	21.9	141.5	143.9	147.0
West Virginia	15.8	15.8	15.8	.4	.4	.4	1.2	1.2	1.2	.5	.5	.5	17.9	17.9	17.9
Total	384.7	374.1	363.6	9.1	10.5	10.6	211.4	224.9	239.7	116.5	116.3	116.3	721.7	725.8	730.2
Regional total	780.0	758.9	748.4	71.1	74.1	76.2	379.2	401.2	427.2	580.3	580.1	585.3	1,810.6	1,814.3	1,837.1
U.S. total	5,555	5,334	5,107	5,752	6,111	6,461	2,406	2,483	2,561	1,681	1,654	1,634	15,393	15,582	15,763
							Percent								
Regional total as percentage of U.S. total	14.0	14.2	14.7	1.2	1.2	1.2	15.8	16.2	16.7	34.5	35.1	35.8	11.8	11.6	11.7

[1]Based on data from tables 11 to 14.

Table 21—Electricity: Potential value of energy from anaerobic digestion of animal and poultry manure[1]

Region and State	1980			1985			1990		
	Electricity[2]	Price[3]	Value	Electricity[2]	Price[3]	Value	Electricity[2]	Price[3]	Value
	gWh	*Cents/kWh*	*$ million*	*gWh*	*Cents/kWh*	*$ million*	*gWh*	*Cents/kWh*	*$ million*
Southeast:									
Alabama	135.0	5.1	6.9	143.2	8.8	12.6	143.8	10.2	14.7
Florida	246.0	5.9	14.5	246.2	10.1	24.9	241.9	11.8	29.7
Georgia	279.1	4.7	13.1	275.6	8.1	22.3	274.7	9.4	25.8
South Carolina	93.0	4.6	4.3	93.6	7.9	7.4	100.0	9.2	9.2
Total	753.1	5.2	38.8	758.6	8.9	67.2	770.4	10.3	79.4
Delta States:									
Arkansas	159.1	4.8	7.6	165.3	8.3	13.7	174.9	9.6	16.8
Louisiana	76.6	4.3	3.3	71.4	7.4	5.3	71.4	8.6	6.1
Mississippi	100.1	4.7	4.7	93.2	8.1	7.5	90.2	9.4	8.5
Total	335.8	4.6	15.6	329.9	8.0	26.5	335.6	9.4	31.4
Appalachian:									
Kentucky	153.7	4.0	6.1	149.3	6.9	10.3	145.3	8.0	11.6
North Carolina	251.5	4.5	11.3	260.6	7.7	20.1	264.6	9.0	23.8
Tennessee	157.1	3.5	5.5	154.1	6.0	9.2	155.4	7.0	10.9
Virginia	141.5	5.1	7.2	143.9	8.8	12.7	140.7	10.2	14.4
West Virginia	17.9	4.3	.8	17.9	7.4	1.3	17.9	8.6	1.5
Total	721.7	4.3	30.9	725.8	7.4	53.6	730.2	8.5	62.2
Regional total	1,810.6	4.7	85.3	1,814.3	8.1	147.3	1,837.1	9.4	173.0
U.S. total	15,393.4	4.7	723.5	15,582.1	8.1	1,262.2	15,762.7	9.4	1,481.7
Regional total as percentage of U.S. total	11.8	—	11.8	11.6	*Percent* —	11.7	11.7	—	11.7

— = Not applicable.

[1]Includes energy from economically recoverable manure from dairy, hogs, feedlot beef, and laying hen enterprises.

[2]Based on data from table 20.

[3]Based on prices paid by farmers by State for 1980 [*36*] and projected U.S. prices for 1985 and 1990 [*40*]. Prices for individual States assumed to increase from 1980 at same percentage rate projected as U.S. average prices. Regional prices are weighted averages.

Table 22—Direct burning: Quantity of economically recoverable thermal energy from poultry litter and manure[1]

Region and State	Broilers			Turkeys			Pullets			Total		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
						Billion Btu						
Southeast:												
Alabama	6,202	7,196	8,187	—	—	—	237	250	256	6,439	7,446	8,443
Florida	1,139	1,384	1,629	—	—	—	250	240	227	1,389	1,624	1,856
Georgia	7,196	8,131	9,066	222	277	333	371	346	314	7,789	8,754	9,713
South Carolina	540	622	703	381	438	495	131	134	141	1,052	1,194	1,339
Total	15,077	17,333	19,585	603	715	828	989	970	938	16,669	19,018	21,351
Delta States:												
Arkansas	8,045	9,694	11,342	1,561	1,951	2,342	387	403	426	9,993	12,048	14,110
Louisiana	1,307	1,614	1,921	—	—	—	22	22	22	1,329	1,636	1,943
Mississippi	3,570	4,160	4,750	—	—	—	154	144	134	3,724	4,304	4,884
Total	12,922	15,468	18,013	1,561	1,951	2,342	563	569	582	15,046	17,988	20,937
Appalachian:												
Kentucky	31	31	31	—	—	—	19	19	19	50	50	50
North Carolina	4,956	5,675	6,394	2,698	3,373	4,048	234	247	259	7,888	9,295	10,701
Tennessee	794	886	976	—	—	—	51	42	42	845	928	1,018
Virginia	1,618	1,958	2,297	963	1,204	1,445	86	90	90	2,667	3,252	3,832
West Virginia	271	324	379	243	291	340	3	3	3	517	618	722
Total	7,670	8,874	10,077	3,904	4,868	5,833	393	401	413	11,967	14,143	16,323
Regional total	35,669	41,675	47,675	6,068	7,534	9,003	1,945	1,940	1,933	43,682	51,149	58,611
U.S. total	50,021	58,274	66,528	17,337	20,978	24,586	4,488	4,501	4,491	71,846	83,753	95,605
						Percent						
Regional total as percentage of U.S. total	71.3	71.5	71.7	35.0	35.9	36.6	43.4	43.1	43.1	60.8	61.1	61.3

— = Data for certain States not available.

[1]Based on data from tables 15 to 17. Reflects 11 to 12 million Btu per ton of manure and litter dry weight.

Table 23—Direct burning: Potential value of thermal energy from poultry litter and manure as a substitute for softwood shavings or LP gas[1]

Region and State	Softwood shavings						LP gas					
	1980		1985		1990		1980		1985		1990	
	Price[2]	Value	Price[2]	Value	Price[2]	Value	Price[3]	Value	Price[3]	Value	Price[3]	Value
	$/MMBtu	*$ million*	*$/MMBtu*	*$ million*	*$/MMBtu*	*$ million*	*Cents/gal*	*$ million*	*Cents/gal*	*$ million*	*Cents/gal*	*$ million*
Southeast:												
Alabama	1.46	9.4	1.95	14.5	2.92	24.6	62.67	42.5	96.20	75.4	122.52	108.9
Florida	1.46	2.1	1.95	3.2	2.92	5.5	78.83	11.6	121.00	20.7	154.11	30.1
Georgia	1.46	11.3	1.95	17.2	2.92	28.4	66.75	54.8	102.46	94.4	130.50	133.4
South Carolina	1.46	1.6	1.95	2.4	2.92	3.9	68.33	7.5	104.89	13.2	133.59	18.9
Total	1.46	24.4	1.95	37.3	2.92	62.4	70.16	116.4	107.70	203.7	137.16	291.3
Delta States:												
Arkansas	1.46	14.6	1.95	23.5	2.92	41.1	63.67	67.0	97.73	123.9	124.47	184.9
Louisiana	1.46	1.9	1.95	3.1	2.92	5.7	70.42	9.9	108.09	18.6	137.67	28.1
Mississippi	1.46	5.4	1.95	8.4	2.92	14.3	67.42	26.4	103.49	47.0	131.81	67.8
Total	1.46	21.9	1.95	35.0	2.92	61.1	66.33	103.3	101.82	189.5	129.68	280.8
Appalachian:												
Kentucky	1.46	.1	1.95	.1	2.92	.2	63.50	.3	97.47	.5	124.14	.6
North Carolina	1.46	11.4	1.95	18.2	2.92	31.3	63.42	52.7	97.35	95.3	123.99	139.7
Tennessee	1.46	1.3	1.95	1.8	2.92	2.9	70.00	6.3	107.45	10.5	136.85	14.7
Virginia	1.46	3.9	1.95	6.3	2.92	11.2	66.58	18.6	102.20	35.1	130.16	52.5
West Virginia	1.46	.8	1.95	1.2	2.92	2.1	66.58	3.5	102.20	6.6	130.16	9.9
Total	1.46	17.5	1.95	27.6	2.92	47.7	63.91	81.4	98.10	148.0	124.94	217.4
Regional total	1.46	63.8	1.95	99.9	2.92	171.2	66.96	301.1	102.78	541.2	130.91	789.5
U.S. total	1.46	104.9	1.95	163.3	2.92	279.2	61.90	468.1	95.02	837.7	121.01	1,217.8
Regional total as percentage of U.S. total	—	60.8	—	61.2	—	*Percent* 61.3	—	64.3	—	64.6	—	64.8

— = Not applicable.

[1]Based on thermal energy data from table 22. One gallon of LP gas yields 95,000 Btu, and 1 ton of softwood shavings yields 11.4 MMBtu [5]. Includes energy from economically recoverable litter and manure from broilers, turkeys, and pullets.

[2]Based on shavings prices of $16.70 per ton delivered or $1.46 per MMBtu usable energy in 1980 [5]; projected prices of $25.05 per ton or $1.95 per MMBtu usable energy in 1985, and $33.40 per ton or $2.92 per MMBtu usable energy in 1990. Regional prices are weighted averages.

[3]Based on prices paid by farmers by State for 1980 [36] and projected U.S. prices for 1985 and 1990. Prices for individual States assumed to increase from 1980 at same percentage rate as projected U.S. average prices. Regional prices are weighted averages.

Total Thermal Energy Production

The total economically recoverable thermal energy potential from livestock and poultry manure in the South was 64.3 trillion Btu in 1980, with 55.4 percent of this energy derived from broilers, 13.8 percent from dairy cows, 10.4 percent from laying hens, 9.4 percent from turkeys, 6.7 percent from hogs, 3 percent from pullets, and 1.3 percent from fed beef (table 24 and fig. 2). This energy potential was based on methane gas production from the dairy, beef, hog, and laying hen enterprises, and direct burning of litter and manure from broiler, turkey, and pullet enterprises. Total energy production from this region was 26 percent of the total potential output from these types of enterprises in the United States in 1980. Major producing States in the region were Arkansas, Georgia, North Carolina, and Alabama, which accounted for 64 percent of the thermal energy potential in the region. However, other States also had significant energy potential except for West Virginia, which had relatively few livestock and poultry enterprises large enough to use modern biomass energy conversion technologies.

The economically recoverable thermal energy potential from these enterprises in the South in 1985 was projected to be 71.8 trillion Btu with most of the increase from 1980 due to expected increases in numbers of broilers and turkeys (table 25 and fig. 2). A slight increase in number of hogs is also expected by 1985, which will increase their potential energy output. Dairy cow numbers are projected to decline somewhat. Fed cattle numbers are expected

Table 24—Thermal energy: Potential quantity of economically recoverable energy from animal and poultry manure and litter, 1980[1]

Region and State	Dairy	Beef	Hogs	Layers	Broilers	Turkeys	Pullets	Total
				Billion Btu				
Southeast:								
Alabama	360	117	280	780	6,202	—	237	7,976
Florida	1,260	341	119	1,080	1,139	—	250	4,189
Georgia	840	121	776	1,440	7,196	222	371	10,966
South Carolina	300	40	238	480	540	381	131	2,110
Total	2,760	619	1,413	3,780	15,077	603	989	25,241
Delta States:								
Arkansas	420	28	343	1,020	8,045	1,561	387	11,804
Louisiana	720	5	28	120	1,307	—	22	2,202
Mississippi	600	54	126	360	3,570	—	154	4,864
Total	1,740	87	497	1,500	12,922	1,561	563	18,870
Appalachian:								
Kentucky	1,200	17	413	120	31	—	19	1,800
North Carolina	804	19	1,343	660	4,956	2,698	234	10,750
Tennessee	1,140	41	308	300	794	—	51	2,634
Virginia	1,020	22	329	240	1,618	963	86	4,278
West Virginia	180	5	14	6	271	243	3	722
Total	4,380	104	2,407	1,326	7,670	3,904	393	20,184
Regional total	8,880	810	4,317	6,606	35,669	6,068	1,945	64,295
U.S. total	63,240	65,477	27,386	19,140	50,021	17,337	4,488	247,089
				Percent				
Regional total as percentage of U.S. total	14.0	1.2	15.8	34.5	71.3	35.0	43.4	26.0

— = Data not available.

[1]Data from tables 11 to 17. Based on methane gas production from dairy, beef, hogs, and laying hens, and direct burning of litter and manure from broilers, turkeys, and pullets. Includes manure from only larger farms. Pasture and handling losses deducted.

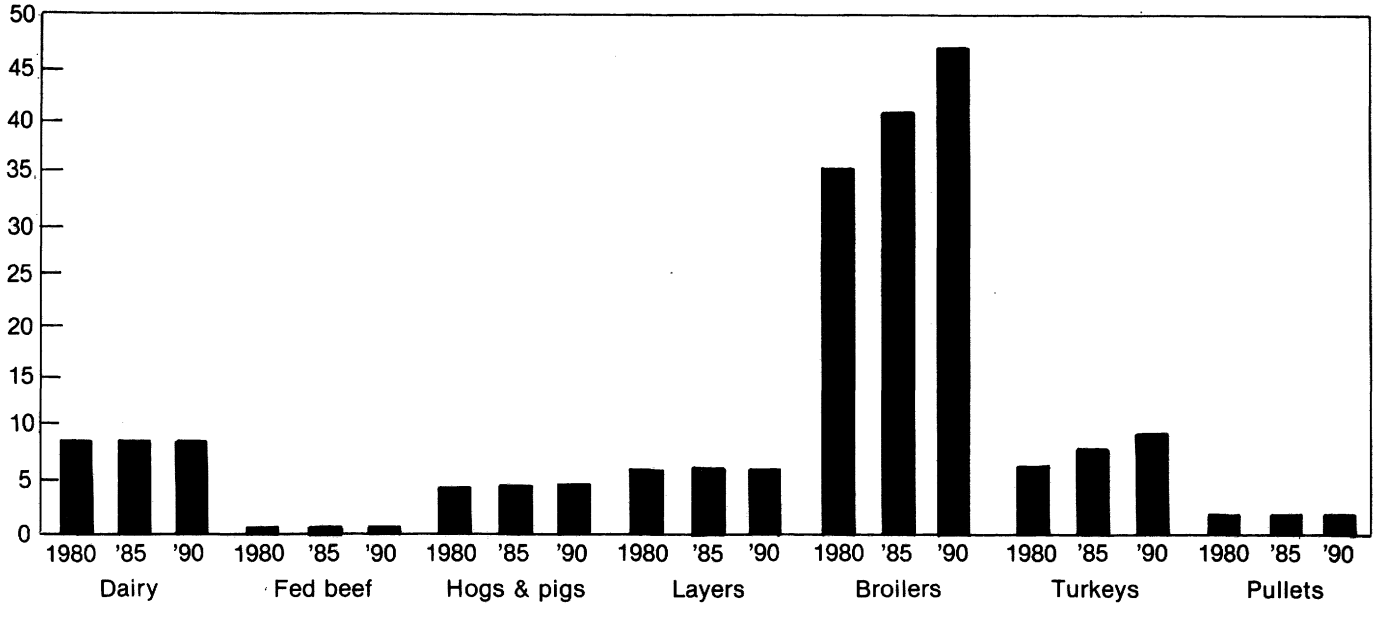
to increase slightly. Little change is expected for laying hen and pullet energy potential from 1980 to 1985 due to little or no change expected in the number of birds on farms. These trends are projected to continue throughout the eighties, thereby increasing the potential economically recoverable thermal energy in the region to 79.5 trillion Btu in 1990 (table 26). Broiler enterprises will then account for 59.9 percent of the thermal energy potential, turkeys for 11.3 percent, dairy cows for 10.7 percent, laying hens for 8.4 percent, hogs for 6.1 percent, pullets for 2.4 percent, and beef for 1.1 percent. The four major producing States in the region are projected to increase their share of potential energy output in the region to 66.3 percent in 1990. The South is projected to increase its share of the total thermal energy potential from these types of enterprises in the United States to nearly 30 percent by 1990.

The potential value of this thermal energy depends on whether it is used to replace natural gas, LP gas, electricity, or wood fuels. The energy values for dairy, fed beef, hogs, and laying hen enterprises are based on anaerobic digestion of manure which produces methane gas that can be used as a substitute for natural gas or LP gas. Or, the methane gas can be used to generate electricity. The energy values for broiler, turkey, and pullet enterprises are based on direct combustion of manure and litter. The lowest use values for energy from all seven of these enterprises in the South would be $344.2 million in 1990 (table 27). In all enterprises with anaerobic digestion processes, the lowest use values were derived from electrical power generation, except for Kentucky in 1980 and the Delta States in 1985 where natural gas was the lowest value substitute. The lowest use values for enterprises using direct burning of litter were based on softwood shavings prices. The highest use values for energy from these seven enterprises are projected to be $1.08 billion in 1990 (table 27). In all cases, the highest values were based on methane gas or direct burning of litter as a substitute for LP gas.

Data in table 27 indicate a wide range of potential economic value from use of biomass energy from livestock and poultry manure. The highest use values are over three times greater than the lowest use values. Market values if this energy were sold

Figure 2

Economically Recoverable Thermal Energy from Livestock and Poultry Manure and Litter, Southern Region, 1980, with Projections for 1985 and 1990[1]



to other potential markets would be even more variable, although market values would probably be somewhat lower than the use values. The total potential economic value for biomass energy from these enterprises in the South will therefore range from $148.5 million at the lowest value in 1980 to as high as $1.08 billion in 1990. For the United States as a whole, these values will range from $828 million in 1980 to $3.5 billion in 1990. With the lowest use values, the South will provide 17.9 to 19.5 percent of the total energy potential value from livestock and poultry wastes in the United States. With the highest use values, the South will provide 27.8 to 30.8 percent of the U.S. total.

Comparative Fertilizer and Feed Values of Manure

Most livestock and poultry manure in the South is now spread on land as a fertilizer supplement, although some litter-based manure and dry waste combinations are used for livestock feed. Even though the plant nutrient values of livestock and poultry manure vary greatly by species and by the condition of the manure, land application is the most common method of using wastes from confined operations, accounting for 75 percent or more of the manure and litter produced in the South in the seventies [*45*]. Given the plant nutrient values existing in the early eighties, the potential fertilizer value of

Table 25—Thermal energy: Potential quantity of economically recoverable energy from animal and poultry manure and litter, 1985[1]

Region and State	Dairy	Beef	Hogs	Layers	Broilers	Turkeys	Pullets	Total
				Billion Btu				
Southeast:								
Alabama	360	143	287	840	7,196	—	250	9,076
Florida	1,260	336	126	1,080	1,384	—	240	4,426
Georgia	840	121	797	1,380	8,131	277	346	11,892
South Carolina	300	40	245	480	622	438	134	2,259
Total	2,760	640	1,455	3,780	17,333	715	970	27,653
Delta States:								
Arkansas	420	43	399	1,020	9,694	1,951	403	13,930
Louisiana	660	5	28	120	1,614	—	22	2,449
Mississippi	540	36	126	360	4,160	—	144	5,366
Total	1,620	84	553	1,500	15,468	1,951	569	21,745
Appalachian:								
Kentucky	1,140	20	420	120	31	—	19	1,750
North Carolina	780	19	1,448	720	5,675	3,373	247	12,262
Tennessee	1,140	55	322	240	886	—	42	2,685
Virginia	1,020	20	357	240	1,958	1,204	90	4,889
West Virginia	180	4	14	6	324	291	3	822
Total	4,260	118	2,561	1,326	8,874	4,868	401	22,408
Regional total	8,640	842	4,569	6,606	41,675	7,534	1,940	71,806
U.S. total	60,720	69,568	28,263	18,840	58,274	20,978	4,501	261,144
				Percent				
Regional total as percentage of U.S. total	14.2	1.2	16.2	35.1	71.5	35.9	43.1	27.5

— = Data not available.

[1]Data from tables 11 to 17. Based on methane gas production from dairy, beef, hogs, and laying hens, and direct burning of litter and manure from broilers, turkeys, and pullets. Includes manure from only larger farms. Pasture and handling losses deducted.

the economically recoverable livestock and poultry manure in the South was $240 million in 1980 (table 28). This fertilizer value is substantially greater than the lowest energy use value of this manure in 1980 ($148.5 million), but it is substantially less than the highest use value for energy ($447.7 million) (table 27). Fertilizer values are also greater than the lowest use energy values for 1985 and 1990, but this margin in favor of fertilizer use is expected to gradually decline due to the more rapid increases in energy prices projected for the eighties. The highest use energy values (LP gas) in 1985 and 1990 are therefore projected to be substantially greater than fertilizer values by amounts of $449.8 million in 1985 and $679.9 in 1990.

Manure and litter can also be used as an ingredient in animal and poultry feeds. Poultry litter or dried manure from caged layers has a significant nutritional value, particularly for feeding ruminants [*8, 19*]. This manure is high in crude protein which can replace soybean meal in various feed rations. The high roughage content of litter is also a good fiber source. Because of lack of standardization in feed-mixing formulas and the possibility of residue contamination, use of animal and poultry manure for feed has not become well established. The most common practices involve feeding broiler litter mixtures to beef cattle. However, potential values for manure and litter when used for livestock and poultry feed are typically twice as great as when used for fertilizer (table 28). Animal feed use is therefore more competitive with the potential energy values from poultry manure, and animal feed values were actually somewhat higher than the highest use energy value for 1980. However, higher projected in-

Table 26—Thermal energy: Potential quantity of economically recoverable energy from animal and poultry manure and litter, 1990[1]

Region and State	Dairy	Beef	Hogs	Layers	Broilers	Turkeys	Pullets	Total
				Billion Btu				
Southeast:								
Alabama	360	143	294	840	8,187	—	256	10,080
Florida	1,260	341	126	1,140	1,629	—	227	4,723
Georgia	840	121	847	1,320	9,066	333	314	12,841
South Carolina	300	40	259	540	703	495	141	2,478
Total	2,760	645	1,526	3,840	19,585	828	938	30,122
Delta States:								
Arkansas	420	43	448	1,080	11,342	2,342	426	16,101
Louisiana	660	5	28	120	1,921	—	22	2,756
Mississippi	540	54	133	300	4,750	—	134	5,911
Total	1,620	102	609	1,500	18,013	2,342	582	24,768
Appalachian:								
Kentucky	1,080	20	434	120	31	—	19	1,704
North Carolina	720	19	1,553	720	6,394	4,048	259	13,713
Tennessee	1,140	55	336	240	976	—	42	2,789
Virginia	1,020	22	392	240	2,297	1,445	90	5,506
West Virginia	180	5	14	6	379	340	3	927
Total	4,140	121	2,729	1,326	10,077	5,833	413	24,639
Regional total	8,520	868	4,864	6,666	47,675	9,003	1,933	79,529
U.S. total	58,140	73,549	29,159	18,600	66,528	24,586	4,491	275,053
				Percent				
Regional total as percentage of U.S. total	14.7	1.2	16.7	35.8	71.7	36.6	43.1	28.9

— = Data not available.

[1]Data from tables 11 to 17. Based on methane gas production from dairy, beef, hogs, and laying hens, and direct burning of litter and manure from broilers, turkeys, and pullets. Includes manure from only larger farms. Pasture and handling losses deducted.

creases in energy prices in the eighties indicate a somewhat greater advantage for energy use values in 1985 and 1990 when compared with animal feed values.

Anaerobic digestion leaves a residue that can also be used as a fertilizer or animal feed ingredient, although the plant nutrient or feed values of this residue are highly variable [*14*]. Therefore, the total value of wastes from enterprises using anaerobic digestion processes will be increased if these residues can be effectively used. In addition to energy values ranging from $203.8 to $290.8 million in 1990, the potential value of residues that could be used for fertilizer could be as high as $163.8 million in 1990. Potential animal feed values of these residues would be even higher, ranging up to $327.6 million in 1990 if all residues could be salvaged and used. However, not all manure residues may be suitable for animal feeding due to possible regulatory restrictions and handling considerations. Use of these residues for animal feeding is not common, but some farms do it. Other uses for residues are possible, but none are widespread. Nevertheless, use of these residues would greatly enhance the economic potential of biomass energy from livestock and poultry enterprises.

Table 27—Thermal energy: Potential total value of thermal energy from anaerobic digestion or direct combustion of animal and poultry manure and litter[1]

Region and State	Lowest use value[2]			Highest use value[3]		
	1980	1985	1990	1980	1985	1990
			Million dollars			
Southeast:						
Alabama	16.3	27.1	39.3	52.6	91.9	130.0
Florida	16.6	28.1	35.2	34.8	56.4	76.6
Georgia	24.4	39.5	54.2	77.1	128.2	176.4
South Carolina	5.9	9.8	13.1	15.1	25.0	34.9
Total	63.2	104.5	141.8	179.6	301.5	417.9
Delta States:						
Arkansas	22.2	32.5	57.9	79.1	143.3	211.0
Louisiana	5.2	8.2	11.8	16.4	27.9	39.9
Mississippi	10.1	15.8	22.8	34.5	58.6	82.0
Total	37.5	56.5	92.5	130.0	229.8	332.9
Appalachian:						
Kentucky	5.6	10.4	11.8	12.0	17.9	22.2
North Carolina	22.7	38.3	55.1	71.8	125.7	179.0
Tennessee	6.8	11.0	13.8	19.5	30.4	40.2
Virginia	11.1	19.0	25.6	29.9	51.6	75.4
West Virginia	1.6	2.5	3.6	4.9	8.8	12.7
Total	47.8	81.2	109.9	138.1	234.4	329.5
Regional total	148.5	247.2	344.2	447.7	765.7	1,080.3
U.S. total	827.8	1,420.5	1,760.9	1,609.8	2,612.0	3,503.8
			Percent			
Regional total as percentage of U.S. total	17.9	17.4	19.5	27.8	29.3	30.8

[1]Thermal energy totals from tables 24 to 26. Values are based on anaerobic digestion of manure from dairy, fed beef, hogs, and laying hen enterprises, and direct combustion of manure and litter from broiler, turkey, and pullet growing enterprises.

[2]Lowest use values for enterprises using anaerobic digestion are from electrical power generation (table 21) except for Kentucky in 1980 and the Delta States in 1985 where natural gas was the lowest value substitute (table 19). Lowest use values for enterprises using direct burning of litter are based on softwood shavings prices (table 23).

[3]Highest use values for energy produced by all enterprises are based on methane gas or direct burning of litter and manure as a substitute for LP gas (tables 19 and 23).

Table 28—Potential fertilizer and feed value of economically recoverable animal and poultry manure and litter[1]

Region and State	Fertilizer value[2]			Animal feed value[3]		
	1980	1985	1990	1980	1985	1990
			Million dollars			
Southeast:						
Alabama	26.00	35.10	45.50	52.50	70.20	91.00
Florida	19.50	23.40	31.85	39.00	46.80	63.70
Georgia	39.00	50.70	63.70	78.00	101.40	127.40
South Carolina	9.75	11.70	13.65	19.50	23.40	27.30
Total	94.25	120.90	154.70	188.50	241.80	309.40
Delta States:						
Arkansas	39.00	54.60	72.80	78.00	109.20	145.60
Louisiana	9.75	11.70	13.65	19.50	23.40	27.30
Mississippi	16.25	23.40	27.30	32.50	46.80	54.60
Total	65.00	89.70	113.75	130.00	179.40	227.50
Appalachian:						
Kentucky	9.75	11.70	13.65	19.50	23.40	27.30
North Carolina	39.00	50.70	63.70	78.00	101.40	127.40
Tennessee	13.00	15.60	18.20	26.00	31.20	36.40
Virginia	16.25	23.40	31.85	32.50	46.80	63.70
West Virginia	3.25	3.90	4.55	6.50	7.80	9.10
Total	81.25	105.30	131.95	162.50	210.60	263.90
Regional total	240.50	315.90	400.40	481.00	631.80	800.80
U.S. total	1,215.50	1,505.40	1,810.90	2,431.00	3,010.80	3,621.80
			Percent			
Regional total as percentage of U.S. total	19.8	21.0	22.1	19.8	21.0	22.1

[1]Economically recoverable manure and litter volumes from tables 11 to 17.
[2]Based on plant nutrient values of $32.50 per ton dry weight for manure and litter in 1980 [*19, 31*] and projected values of $39 per ton in 1985 and $45.50 per ton in 1990.
[3]Based on animal feed values of $65 per ton dry weight for manure and litter in 1980 [*8, 19*] and projected values of $78 per ton in 1985 and $91 per ton in 1990.

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